MEMORANDUM REPORT BRL-MR-3838

BRL

COMPARISON OF 155-MM GUN TUBE HEAT INPUT WITH SOLVENTLESS AND SOLVENT PROPELLANT

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JUNE 1990

U.S. ARMY LABORATORY COMMAND

BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

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13. ABSTRACT *(Maximum 200 words)*

A test to measure wall temperatures of a 155-mm howitzer cannon was conducted at the Ballistic Research Laboratory as part of a Product Improvement Program (PIP) which was formulated and conducted under the auspices of the Armament Research, Development, and Engineering Center. The main objective of this ballistic study was to determine if the projected gun tube wear from an alternative, ballistically equivalent, 155-mm, M203A1 propelling charge containing solventless stick propellant is comparable to the wear produced by the standard M203A1 containing M31A1E1 solvent based propellant. The results of this study indicate that the solventless propellant charge does not appear to be more erosive than the standard M203A1 charge. Additionally, the effects of several of the charge constituents on the amount of heat transferred to the tube were investigated, with a particularly dramatic increase seen in heat transferred to the tube when the case was removed.

14. SUBJECT TERMS

155-mm; M199 Cannon; Gun Wear; Solventless Propellant (XM41); M203A1; Heat Input; Erosion

15. NUMBER OF PAGES

71

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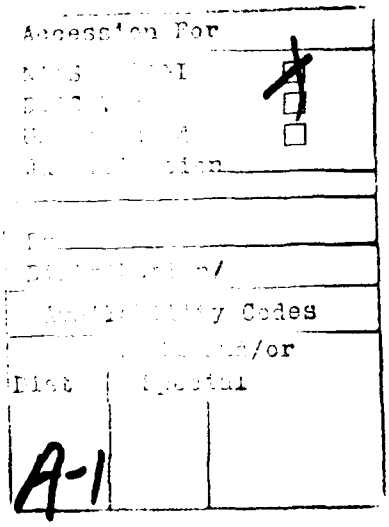

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LIST OF FIGURES

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I. INTRODUCTION

The M203A1, shown in Figure 1, is a 155-mm, single increment, top zone propelling charge. The charge contains approximately 11.79 kg of M31A1E1 triple base, slotted single perforated stick propellant and a lead foil/wax/TiO_2 liner which acts as a decoppering agent and wear reducing additive. The propellant and liner are contained in a rigid nitrocellulose combustible case which contains talc in its composition for wear reduction purposes. Ignition is accomplished with a CBI/black powder basepad held in place by a combustible end cap. The M203A1 propelling charge was type classified on 29 March 1985 to replace the granular M203 (bag) propelling charge. A PIP is currently being conducted on this 155-mm, stick propelling charge by the Armament Reseafch, Development, and Engineering Center (ARDEC). This PIP would provide an alternate solventless stick propellant for the M203A1 propelling charge. An ARDEC-developed solventless propellant, XM41, was selected as the candidate for the PIP, which will complete full scale evaluation and result in type classification of the alternative propellant in the M203A1 configuration. The charge expected to result from this PIP is shown in Figure 2.

ARDEC initiated several investigations to determine the applicability of solventless propellants to the M203A1 charge configuration and performance level. Such a charge, manufactured at currently under-utilized facilities, would significantly contribute to the number of charges available to support mobilization requirements. Additionally, solventless propellants retain their extruded dimensions with less distortion than solvent propellants, leading to better physical uniformity, thus reducing the labor and cost of blending propellants to obtain the required ballistic uniformity. ARDEC-sponsored investigations include propellant producibility, ballistic acceptability, safety and other charge design related areas. As part of this series of investigations, ARDEC requested that the Ballistic Research Laboratory (BRL) examine the effect on wear of the substitution of the solventless propellant for the standard M31A1E1 propellant.

In the BRL portion of the evaluation of the M203A1 solventless stick propelling charge, gun tube wall temperatures were measured to determine if the heat input into the cannon with this charge was comparable to that with the 155-mm, M203A1, stick propelling charge. From previous ballistic data, it was determined that eliminating the combustible case[1] and additive liner[2] lowers pressure but increases the heat input into the cannon near the origin of rifling, thus increasing wear and erosion. Utilizing this information, possible charge variations were developed to examine the effect of several charge components on the heat transferred to the gun tube.

II. EXPERIMENTAL

A charge test matrix was developed by ARDEC and BRL to compare heat input from a solventless charge with similar components to that from a standard M203A1 charge. Further, an attempt was made to determine what effect the addition of flash-reducing agents and the removal of the wear-reducing liner or combustible case would have on the heat input to the gun wall.

A. Test Matrix

The ballistic test consisted of fourteen, control, M203A1, *solvent* stick propelling charges, Lot IND85M738-1B-3 and twenty eight, experimental, M203A1, *solventless* stick propelling charges. ARDEC-

CHARGE, PROPELLING, 155MM, M203A1
(TC-STD)
(COMMENCE PRODUCTION FY86)

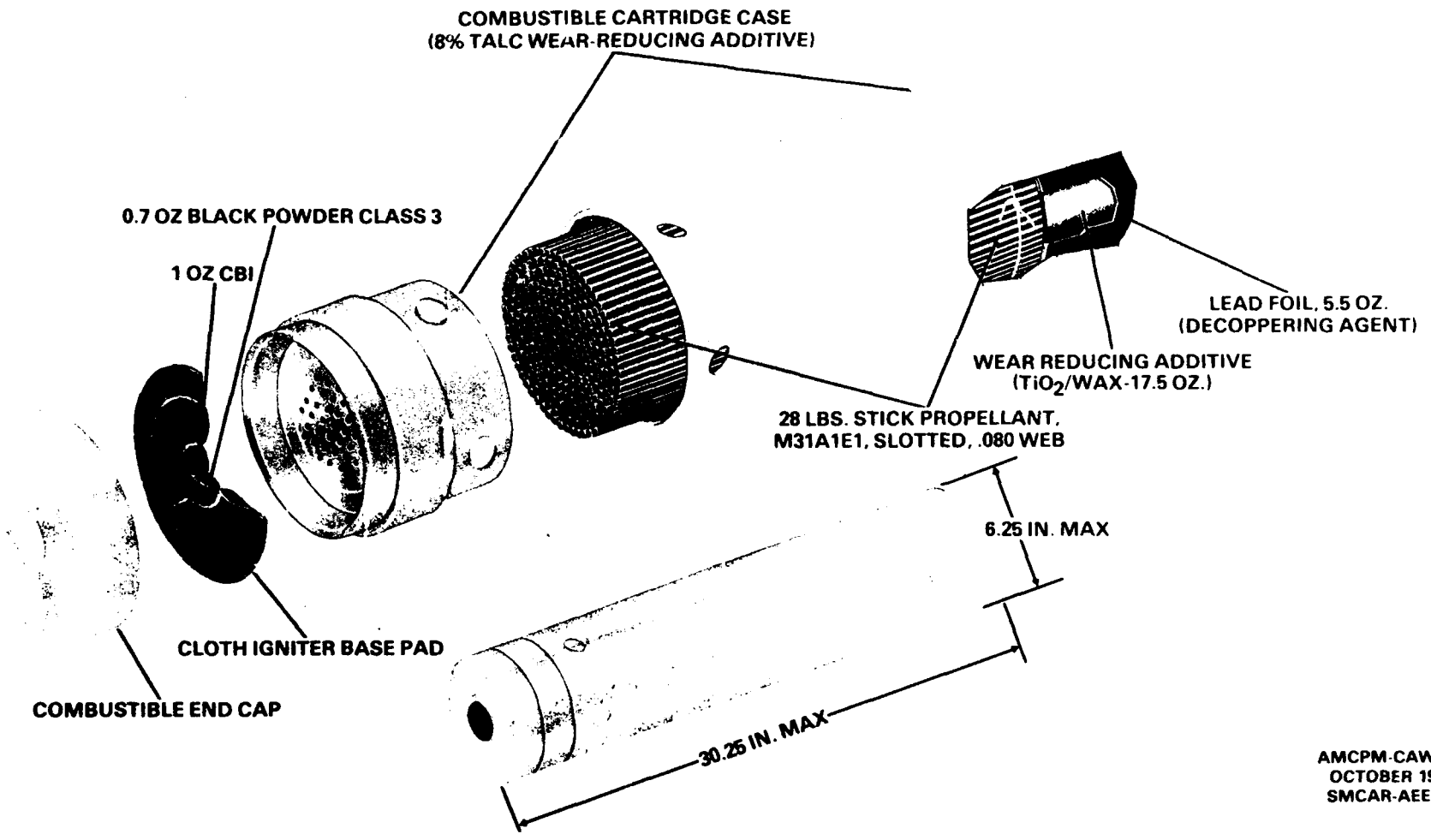

Figure 1. 155-mm, M203A1 Propelling Charge

CHARGE, PROPELLING, 155MM, M203A1
SOLVENTLESS STICK PROPELLANT ALTERNATE

(PIP 1-83-09-7801)

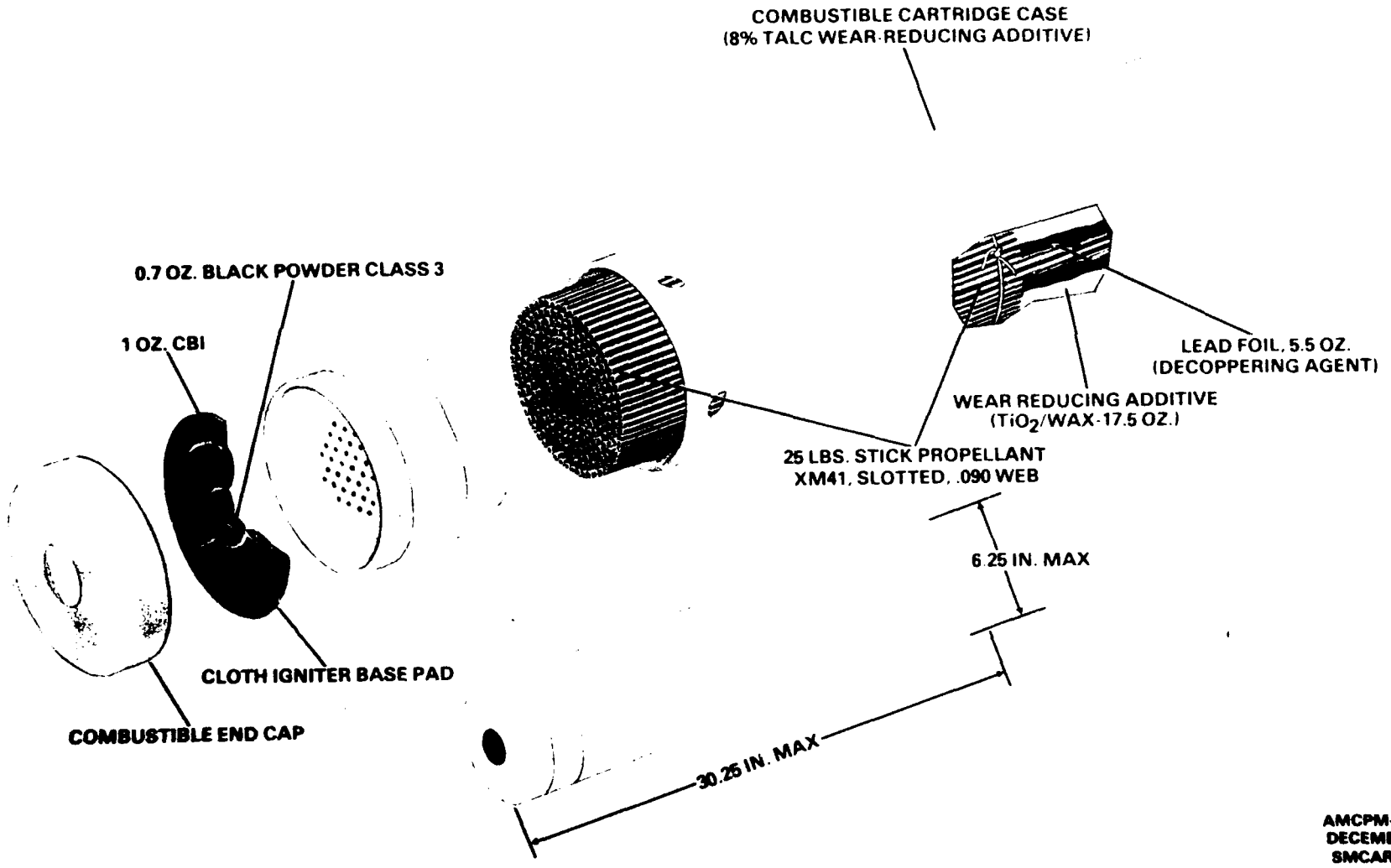

Figure 2. 155-mm, M203A1 Solventless PIP Propelling Charge

developed XM41, solventless, slotted stick propellant, Lot RAD-PD-736-8C was used in all the solventless experimental charges. PXR6325 projectiles, Lot IOP86D002S067, were used with both the solventless and solvent charges. All charges were conditioned at twenty one degrees Celsius for twenty four hours prior to firing.

The solventless charges were subdivided into five sets, consisting of the following components:

1. **Variation 1.** Seven charges contained 11.39 kg of solventless propellant, a combustible case, basepad, and TiO_2/wax liner.

2. **Variation 2.** Seven charges contained 11.39 kg of solventless propellant, a combustible case, and basepad.

3. **Variation 3.** Six charges contained 11.39 kg of solventless propellant, a combustible case, basepad, TiO_2/wax liner, and a 0.113-kg KNO_3 flash reducer.

4. **Variation 4.** Seven charges contained 11.39 kg of solventless propellant, a combustible case, basepad, TiO_2/wax liner, and a 0.113-kg K_2SO_4 flash reducer.

5. **Variation 5.** One charge contained 11.39 kg of solventless propellant and a basepad.

B. Test Firings

The gun firings were conducted at the Ballistic Research Laboratory's Sandy Point Firing Facility (R-18), in a 155-mm, M199 cannon, serial no. 32000. The M199 cannon was modified to accept two Kistler 607C4 piezoelectric pressure transducers and five thermocouples. Chamber pressure measurements were made by modifying the M199 cannon's spindle to accept one pressure transducer and machining a threaded port 904.2 mm from the rear face of the tube (RFT) at the 12 o'clock position to accommodate the second pressure transducer in the tube sidewall. A schematic showing the gage and thermocouple locations is given in Figure 3.

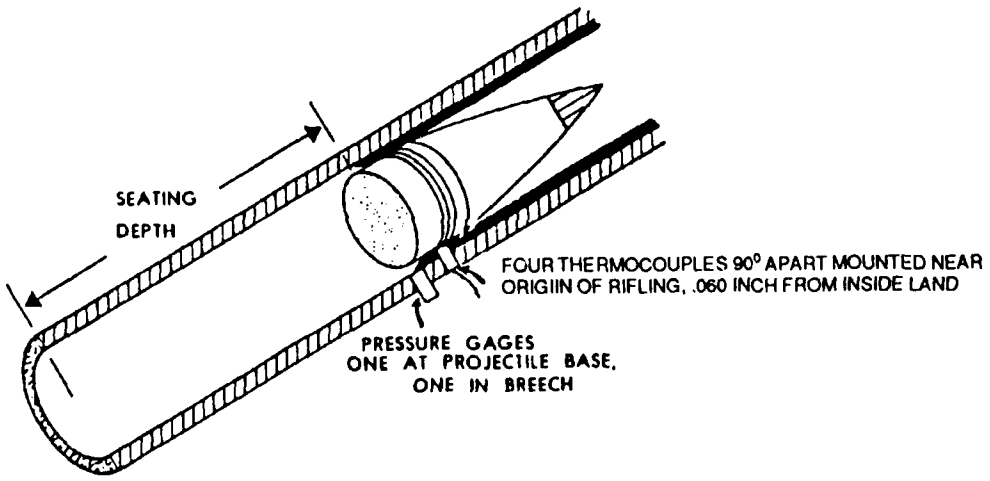

Figure 3: Gage and Thermocouple Schematic

To obtain the heat input measurements, holes were drilled in the gun tube sidewall at the desired thermocouple locations to a depth at 1.59 mm from the bore surface. Constantan wires 0.13 mm in diameter were welded to the bottoms[6] of the holes using a capacitive discharge technique to form constantan-gun steel thermocouples near the bore surface. Four thermocouples were located at 3, 6, 9, and 12 o'clock positions at a distance of 1060 mm from the RFT at the origin of rifling. An additional downbore thermocouple was located at 12 o'clock at 1524 mm from the RFT. This technique was initially developed by Brosseau[3] to measure wall temperatures in 37-mm guns. The technique was modified for this M199 cannon to determine the extent of asymmetric heating in a 155-mm howitzer.[4] The asymmetric heating study provided a reasonable data base for the evaluation of solventless heating.

A calibration factor of 52 microvolts per degree Kelvin was used to compare known voltage calibration steps to the response of the thermocouples. The maximum temperature change for each thermocouple was noted for each round. The heating effects of the various rounds in this study, as well as in Reference 4, were expressed in the maximum temperature change. The maximum temperature change at each thermocouple is a reasonable measure of heat input from the various charges since all the rounds had similar maximum pressures and pressure durations. Given the pressure similarities, the assumption was made that the heat input took place in the same amount of time for all of the rounds.

A 15-GHz continuous wave doppler radar and discriminator were used to obtain on-line velocity/time records.

The maximum breech and forward pressures, differential pressure, projectile velocity and change in temperatures were recorded and reduced by the Ballistic Data Acquisition System (BALDAS) under the control of a PDP 11/45 minicomputer.

III. RESULTS

The maximum pressures, muzzle velocities and sample sizes for all the firings are summarized in Table 1. The maximum temperature changes for the thermocouples at three positions at the origin of rifling are summarized in Table 2. The two other thermocople positions - origin of rifling at 9 o'clock and downbore - are not included due to the failure of the thermocouple junction at these positions for most of the rounds.

Variation 1 was the substitution of solventless propellant for the standard M31A1E1 stick propellant. Breech pressure-time and pressure difference (forward - rear gages) plots are given for the standard M203A1 and the solventless propellant M203A1 in Figures 4 and 5 respectively. A complete record of the pressure-time curves and thermocouple plots are contained in Appendix B. The maximum pressure and muzzle velocity were higher for the solventless variation in comparison to the standard M203A1 charge. The cause of these higher values was attributed to the fact that the solventless charges were fired with 0.3 kg more propellant than was required to ballistically match the M203A1 charge. The maximum change in temperatures with these charges agreed within the scatter of the data with the standard charge, indicating no effect on thermal erosion produced by substitution of the solventless propellant for the solvent propellant. The temperature-time traces for a solventless M203A1 firing are given in Figure 6. These traces are typical of all those obtained in this study.

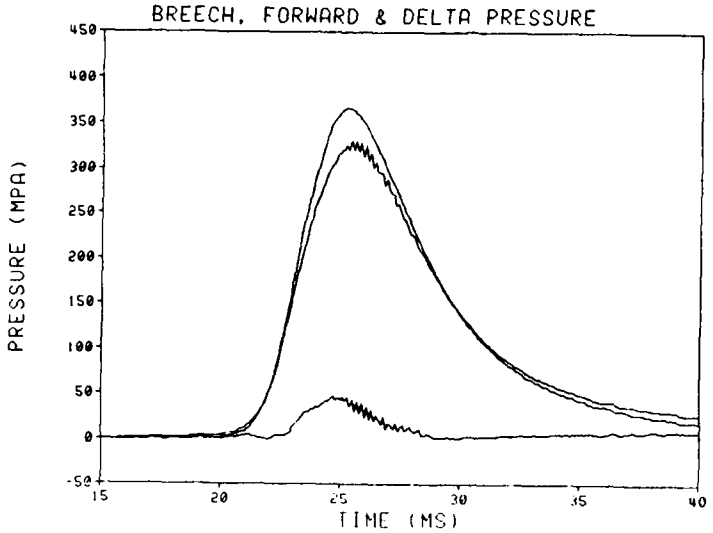

Figure 4: Breech Pressure and Pressure Difference, Standard M203A1

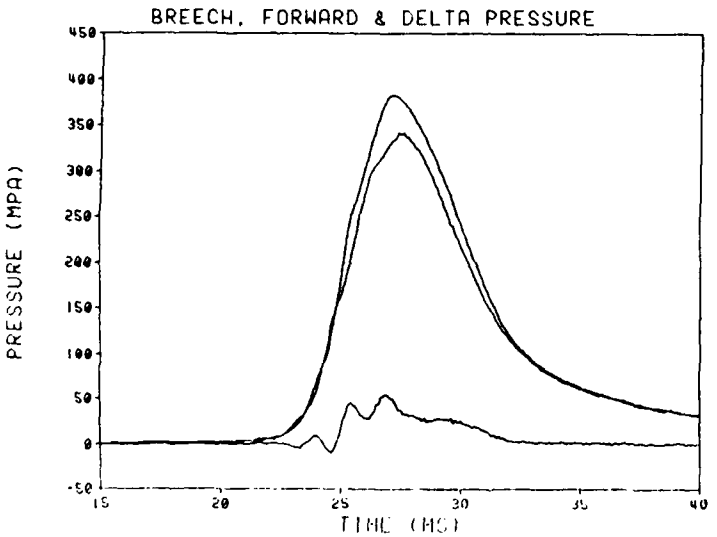

Figure 5: Breech Pressure and Pressure Difference, Solventless M203A1

Charge	Sample Size	Breech Pressure (MPa)	Forward Pressure (MPa)	Muzzle Velocity (m/s)
M203A1	14	366	325	827
Solventless/ liner	7	380	334	839
Solventless/ wo liner	7	364	321	835
Solventless/ KNO_3	6	384	350	844
Solventless/ K_2SO_4	7	382	340	841
Solventless/ no case	1	297	262	794

Table 1. Pressures and Velocity

Charge	Sample Size	Max Temp Rise (°C) 12	3	6	Avg at Origin
M203A1	14	113±8	81±3	108±3	101±5
Solventless/ liner	7	116±8	82±3	114±4	104±3
Solventless/ wo liner	7	119±6	87±2	120±3	110±4
Solventless/ KNO_3	6	115±5	83±2	113±2	105±3
Solventless/ K_2SO_4	7	116±8	82±2	111±2	105±5
Solventless/ no case	1	139	--	138	133±10

Table 2. Thermocouple Data

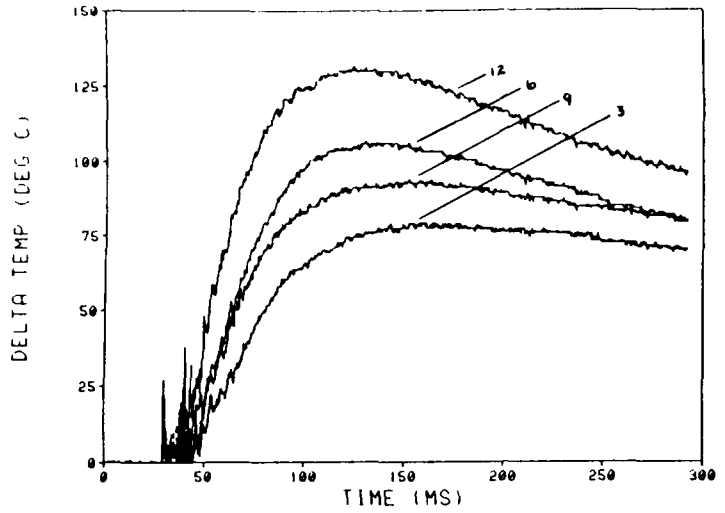

Figure 6: Temperature Changes at Thermocouple Locations 1-4

Variation 2 was the solventless charge without the TiO_2/wax/lead liner. As expected from previous experience with the M203A1, this variation resulted in reduced pressures and velocities in comparison to those from Variation 1. This reduction should be expected, since the elimination of the liner effectively increased the chamber volume. The temperature measurements were slightly higher at all of the thermocouple positions. The temperature results indicate the minimal effect of the wear reducing additive in this charge.

Variations 3 and 4 were the solventless charges with flash reducers of KNO_3 or K_2SO_4. Higher pressures and velocities were seen with the flash reducer shots when compared with other solventless rounds due to the reduction of free chamber volume. The flash reducers produced no effect on the temperature increases.

Variation 5 consisted of a solventless charge without the combustible cartridge case. The pressures and velocities were less than the other solventless rounds due to reduction of the amount of energetic material in the charge and the effective increase in chamber volume due to the elimination of the case and parasitic components. The maximum temperature at the two measured positions increased dramatically over the other solventless charges. These results were anticipated because the combustible case has a flame temperature near 2200 K while the flame temperature of the solventless propellant is approximately 2737 K. The combustible case not only reduces the effective flame temperature of the entire charge, but has an added cooling effect in that gases from its combustion are produced near the boundary layer, the characteristics of which govern the heat input to the tube.

IV. CONCLUSIONS

From the data gathered in this study, we can draw several conclusions regarding the effect several of the charge constituents have on the amount of heat transferred to the gun tube during the interior ballistic cycle.

A combustible-cased charge containing solventless XM41 propellant does not appear to be more erosive than the standard M203A1 charge containing M31A1E1 stick propellant, based on the amount of heat input at the origin of rifling.

The wear reducing additive in the solventless charge reduces the maximum temperature change, and thus the heat input, at the origin of rifling. The magnitude of the reduction appears small; however, testing performed during the M203A1, product improvement program predicted a wear life significantly lower without the liner.

The addition of a flash reducer in the amount typical of that in a fielded charge (0.113 kg) does not affect the amount of heat transferred to the gun tube. It does, however, increase the maximum chamber pressure to the degree expected.

The elimination of the combustible cartridge case significantly increases the heat input at the origin of rifling, as expected. The cooling effect of the entrainment of the case gases, which are cooler than those of the propellant, into the boundary layer was dramatically demonstrated by the the comparison of the temperature rise in the vicinity of the origin of rifling with cased and uncased charges.

REFERENCES

1. T.L. Brosseau, I.C. Stobie, J.R. Ward and R.W. Geene, "120-mm Gun Heat Input Measurements," BRL-TR-02413, US Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, July 1982.

2. F.A. Vassallo, "An Evaluation of Heat Transfer and Erosion in the 155-mm M185 Cannon," Technical Report No. VL-5337-5-1, Calspan Corporation, Buffalo, NY, July 1976.

3. T.L. Brosseau, "An Experimental Method of Accurately Determining the Temperature Distribution and Heat Transferred in Gun Barrels," BRL-R-1740, US Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, September 1974.

4. D.L. Kruczynski, "Gun Tube/Charge/Projectile Interactions and Gun Tube Wear," BRL-TR-3004, US Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, June 1989.

ACKNOWLEDGEMENTS

The authors wish to thank the crew at Range 18 - Messrs. J. Bowen, J. Hewitt, J. Stabile, R. May, J. Tuerk, D. Meier, and S. Little - for the experimental support in conducting the firing program.

APPENDIX A

Description Sheets for XM41 and M31A1E1 Propellants

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PROPELLANT DESCRIPTION SHEET

DRAFT

DISPOSITION CONTROL SYMBOL: EXEMPT-PARA 7-2e AR 335-15

NOMENCLATURE: XM41 Slotted Stick	DA LOT NUMBER: RAD-PE-736- 8C
SPECIFICATION: COR Ltr SMCRA-EN dated 10/11/85	PACKED AMOUNT: 3720 lb
MFG AT: RADFORD ARMY AMMUNITION PLANT, RADFORD, VA.	CONTRACT NUMBER: DAAA09-77-C-4007

DRAFT

NITROCELLULOSE

ACCEPTED BLEND NUMBERS	NITROGEN CONTENT	KI STARCH (65.5°C)	STABILITY (134.5°C)
B-95057	MAX ____ %	____ MIN	____ MIN
	MIN ____ %	____ MIN	____ MIN
	AVG 13.06 %	45+ MIN	30+ MIN
			EXPLOSION ____ MI

MANUFACTURE OF SOLVENTLESS

PERCENTAGE REMIX TO WHOLE 0%

TEMPERATURE ° FROM	TO	PROCESS - DRYING	TIME DAYS	TIME HOURS
Ambient	120	Loading		
	120	Curing		4
120	Ambient	Unload		

PROPELLANT COMPOSITION — TESTS OF FINISHED PROPELLANT

CONSTITUENT	PERCENT FORMULA	PERCENT TOLERANCE	PERCENT MEASURED
Nitrocellulose	42.68		40.9
Nitroguanidine	20.00	± 1.0	21.0
Nitroglycerin	26.50		26.7
Di-normal-propyl-adipate	8.00		8.6
Ethyl Centralite	1.40	± 0.1	1.4
Carbon Black	0.10		0.2
Candelilla Wax	0.10		0.1
Potassium Sulfate	1.22		1.1
Moisture	0.4	Max	0.11

STABILITY AND PHYSICAL TESTS

	FORMULA	ACTUAL
HEAT TEST 120°C		60+
No Fumes		1 hr
FORM OF PROPELLANT	Cyl Slotted Stick	
Taliani - Slope		
of P-T 100 min	< 1.0	0.493
HOE	855±12	860.5
Ignition Temp	Flame °C	193.1
Absolute Density g/cc		1.58

CLOSED BOMB Dynamic

TEST	LOT NUMBER	TEMP °F	RELATIVE QUICKNESS	RELATIVE FORCE
	PE-736-8C	+145	113.56	103.57
	PE-736-8C	+90	103.99	102.94
	PE-736-8C	-40	91.86	101.56
STANDARD	070077	+90	100.00%	100.00%

REMARKS

0.15 gm/cc loading denisty in the 700 cc closed bomb

PROPELLANT DIMENSIONS (inches)

	SPECIFICATION	DIE	FINISHED	of Mean Dimension SPEC.	ACTUAL
LENGTH (L)	29.125±0.125		29.156		
DIAMETER (D)	0.278±0.004	0.278	0.279		2.58
PERF. DIA. (d)	0.110	0.110	0.111		
Web	0.084±0.001	0.084	0.084		
Web Difference /Std. Dev. in % of Web Avg.					
L:D		N/A	104.5		
D:d		N/A	2.50		

DATES
Unblended 4/2/86
Blended 4/20/86
SAMPLED 4/2/86-4/20/86
TEST FINISHED 4/22/86
OFFERED 4/23/86
DESCRIPTION SHEETS FORWARDED 4/23/86

TYPE OF PACKING CONTAINER: Barrier Bag and Wooden Boxes

REMARKS

Per scope of work: Box 1 to 14 unblended (840 lb)
Box 15 to 62 blended (2880 lb)

Nitroglycerin manufactured by RAAP; Nitroguanidine manufactured by Sunflower AAP

SIGNATURE OF CONTRACTOR'S REPRESENTATIVE: E. J. Norris

SIGNATURE OF GOVERNMENT QUALITY ASSURANCE REPRESENTATIVE:

ARRCOM FORM 214P 10 AUG 77

PROPELLANT DESCRIPTION SHEET

EXEMPT: PARA 7-20 AR 385-10

COMPOSITION: M31A1E1 Slotted Stick Propellant
DESCRIPTION: COR Letter SARRA-EN dated 27 September 1983
MFG AT: RADFORD ARMY AMMUNITION PLANT, RADFORD, VA.
LOT NUMBER: RAD PE-738-1B
PACKED AMOUNT: 29,760 pounds
CONTRACT NUMBER: DAAA09-77-C-4007

NITROCELLULOSE

ACCEPTED BLEND NUMBERS: M31,147 M31,322 M31,359 B 31,361 B 31,362 B 31,369 B 31,372 B 31,377 B 31,384 B 31,386 B 31,388

	NITROGEN CONTENT	EI STARCH (65.5°C)	STABILITY (134.5°C)
MAX	12.70 %	____ MIN	____ MIN
MIN	12.53 %	____ MIN	____ MIN
AVG	12.59 %	45+ MIN	30+ MIN
			EXPLOSION MIN

MANUFACTURE OF SOLVENT PROPELLANT

18.16 POUNDS SOLVENT PER POUND NC/DRY WEIGHT INGREDIENTS CONSISTED OF 60 POUNDS ALCOHOL AND 40 POUNDS acetone PER 100 POUNDS SOLVENT PERCENTAGE RATIO TO WHOLE 13.25

TEMPERATURES °F FROM	TO	PROCESS--SOLVENT RECOVERY AND DRYING	TIME DAYS	TIME HOURS
ambient	ambient	Ambient hold		48
ambient	100	Increase at 5°F per hour		25
100	100	Hold on temperature		4
100	ambient	Cool down for processing		

PROPELLANT COMPOSITION				TESTS OF FINISHED PROPELLANT	STABILITY AND PHYSICAL TESTS	
CONSTITUENT	PERCENT FORMULA	PERCENT TOLERANCE	PERCENT OBTAINED		FORMULA	ACTUAL
Nitrocellulose	21.50	± 1.30	21.60	HEAT TEST	40'	CC 60' +
Nitroglycerin	18.00	± 1.00	18.08	No fumes	60'	NF 1 hr
Nitroguanidine	54.70	± 1.00	54.70	FORM OF PROPELLANT	Slotted Stick	
				No. of Perfs	1	1
Dibutylphthalate	3.00	± 0.30	2.95	Avg Wt., g	n/a	33.16
Ethyl Centralite	1.50	± 0.30	1.50	BOE, cal/g	n/a	852.9
Potassium Sulfate	1.25	± 0.30	1.09	Abs. dens. g/cc	n/a	1.67
Carbon Black	0.05	± 0.02	0.05			
Ash			0.03			
TOTAL	100.00		100.00			
Total Volatiles (TV)	0.30	max	0.06			

TEST	LOT NUMBER	TEMP °F	RELATIVE VIGOROUSNESS	RELATIVE FORCE
	RAD-PE-738-1B	+90	95.73	101.94
STANDARD	70077	+90	100.00%	100.00%

REMARKS: Tested in a 700 cc closed bomb, at a 0.2 g/cc loading density.

	SPECIFICATION	DIE	FINISHED	MEAN VAL IN % OF SPEC TOLERANCE SPEC	ACTUAL
LENGTH (L)	29.0	29.0	28.96	n/a	-
DIAMETER (D)	0.250	0.272	0.249	n/a	-
PERF. DIA. (d)	0.086	0.096	0.0853		
Web	0.082	0.088	0.0833		
Web Difference /Std. Dev. in % of Web Avg.	n/a	n/a	n/a		
L/D	116.00	n/a	116.30		
D/d	2.91	n/a	2.92		

DATES: PACKED 12/22/83; SAMPLED 12/22/83; TEST FINISHED 1/11/84; OFFERED; DESCRIPTION SHEETS FORWARDED 23 Mar 84

TYPE OF PACKING CONTAINER: 496 Boxes @60 lbs. each.

REMARKS: This lot meets specification requirements.

SIGNATURE OF CONTRACTOR'S REPRESENTATIVE: J. C. COKER

SIGNATURE OF GOVERNMENT QUALITY ASSURANCE REPRESENTATIVE: J. E. BLAND

ARRCOM FORM 214R 10 AUG 77 SEQUENCE No. 373

APPENDIX B

Computer generated plots of breech, forward, and delta (breech minus forward) pressures, and thermocouple output.

(Plots are in order of firing).

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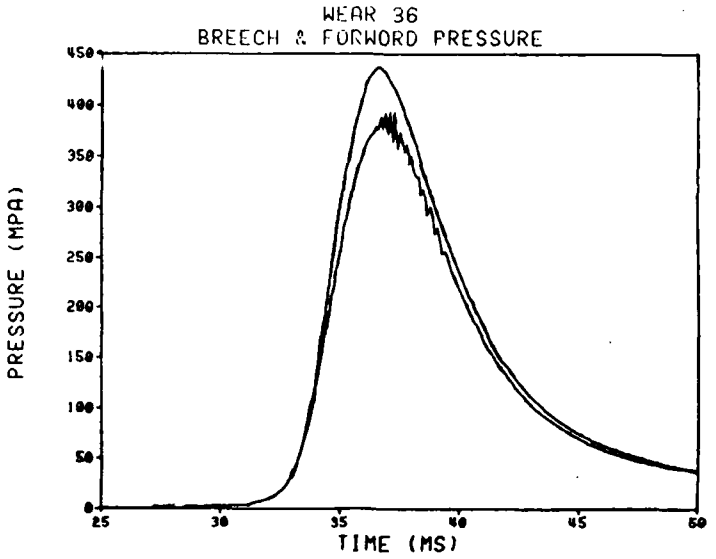
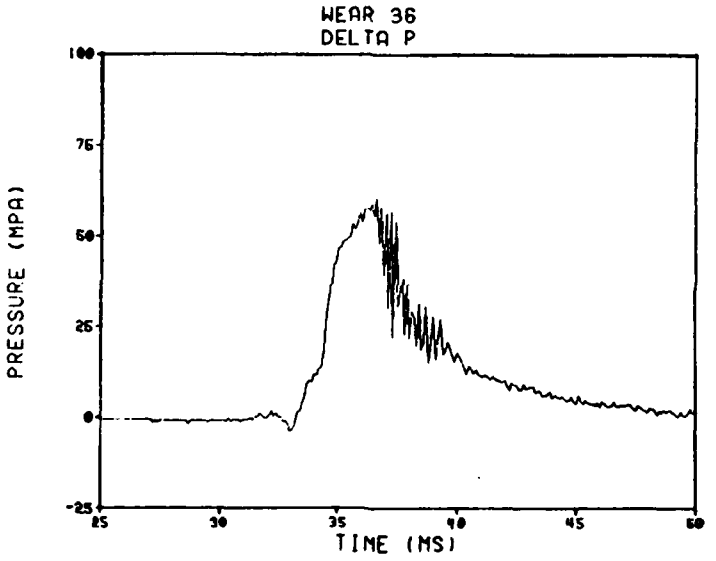
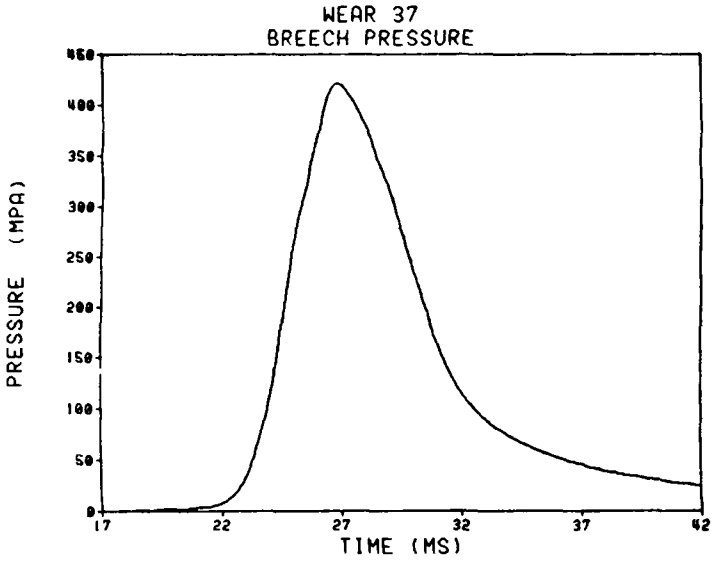
RD #	PROPELLANT TYPE	LINER Yes/No	FLASH REDUCER
36	M31A1E1	Y	---
37	XM41	Y	---
38	M31A1E1	Y	---
39	XM41	N	---
40	M31A1E1	Y	---
41	XM41	N	---
42	XM41	Y	---
43	M31A1E1	Y	---
44	M31A1E1	Y	---
45	XM41	Y	---
46	XM41	N	---
47	M31A1E1	Y	---
48	XM41	Y	K_2SO_4
49	XM41	Y	KNO_3
50	M31A1E1	Y	---
51	XM41	Y	K_2SO_4
52	XM41	Y	KNO_3
53	M31A1E1	Y	---
54	XM41	Y	K_2SO_4
55	XM41	Y	KNO_3
56	M31A1E1	Y	---
57	XM41	Y	K_2SO_4
58	XM41	Y	KNO_3
59	M31A1E1	Y	---
60	XM41	Y	---
61	XM41	N	---
62	M31A1E1	Y	---
63	XM41	Y	---
64	XM41	N	---
65	XM41	Y	---

RD #	PROPELLANT TYPE	LINER Yes/No	FLASH REDUCER
66	XM41	N	---
67	XM41	Y	---
68	XM41	N	---
69	M31A1E1	Y	---
70	XM41	Y	---
71	XM41	N	---
72	XM41	Y	K_2SO_4
73	XM41	Y	KNO_3
74	M31A1E1	Y	---
75	XM41	Y	K_2SO_4
76	XM41	Y	KNO_3
77	M31A1E1	Y	---
78	XM41	Y	K_2SO_4

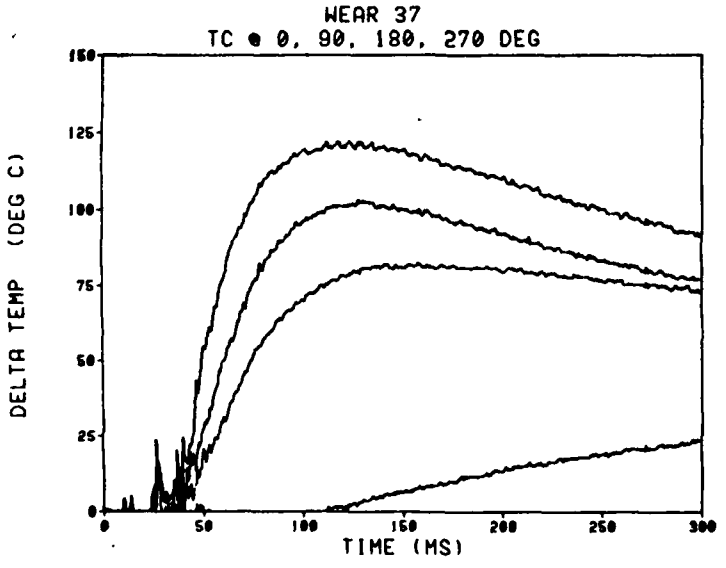

WEAR 36
BREECH & FORWORD PRESSURE
PRESSURE (MPA)
450
400
350
300
250
200
150
100
50
0
25
30
35
40
45
50
TIME (MS)

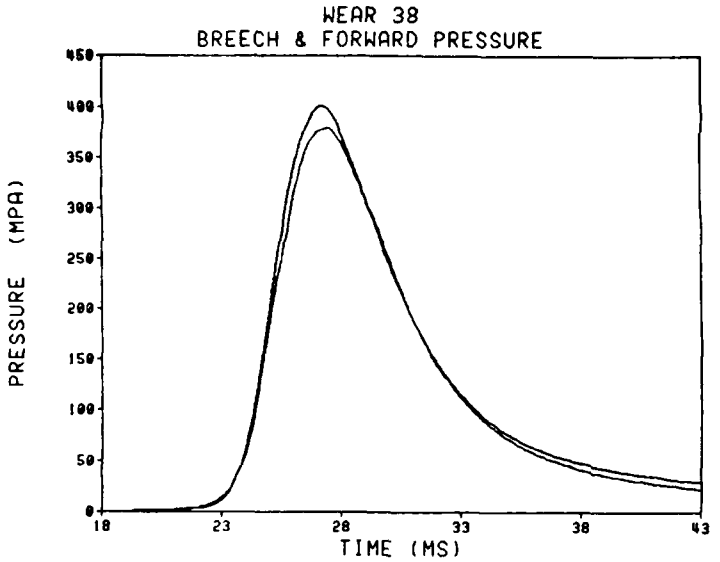

WEAR 36
DELTA P
PRESSURE (MPA)
100
75
50
25
0
-25
25
30
35
40
45
50
TIME (MS)

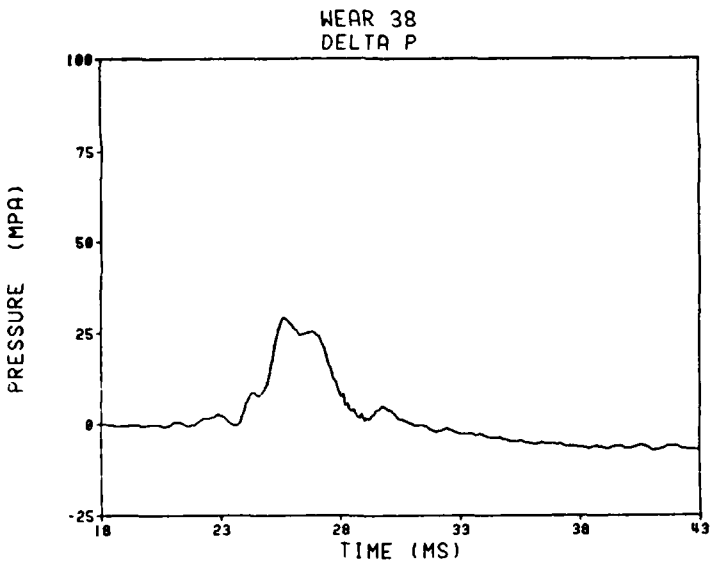
DATA LOST

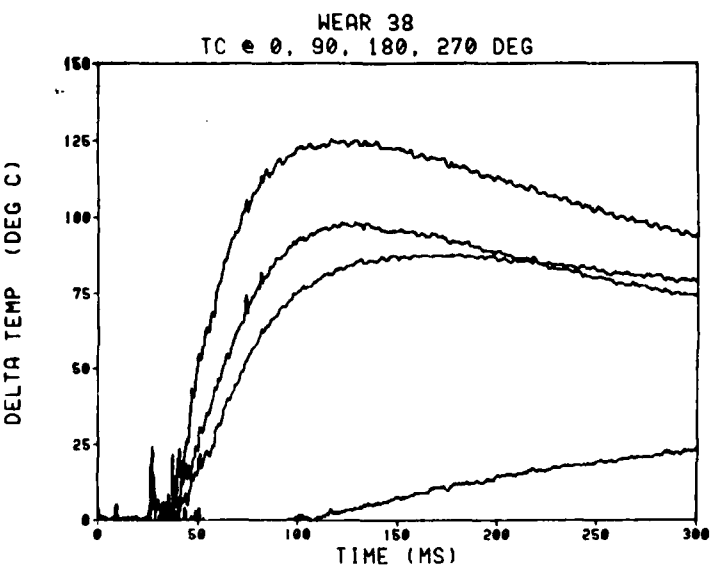

WEAR 37
BREECH PRESSURE
PRESSURE (MPA)
450
400
350
300
250
200
150
100
50
0
17
22
27
32
37
42
TIME (MS)

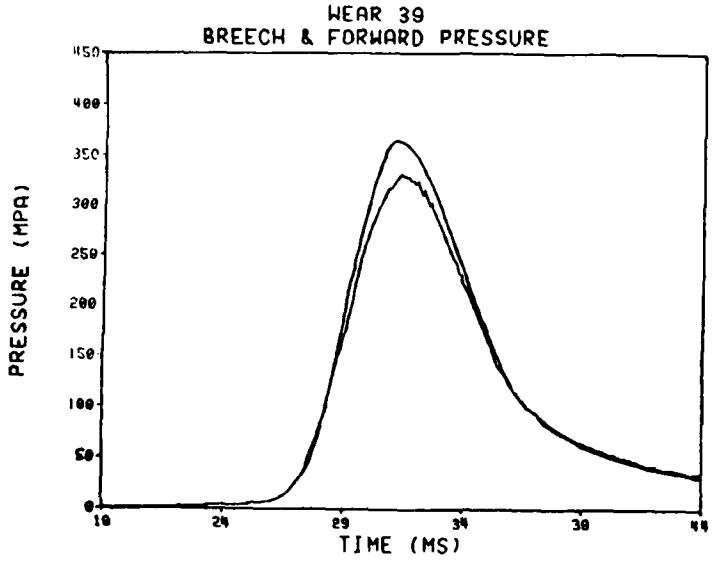
DATA LOST

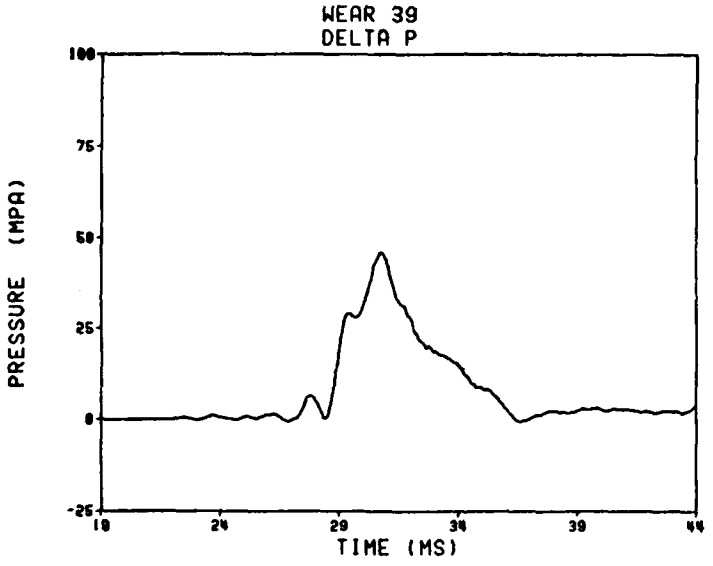

WEAR 37
TC @ 0, 90, 180, 270 DEG
DELTA TEMP (DEG C)
150
125
100
75
50
25
0
0
50
100
150
200
250
300
TIME (MS)

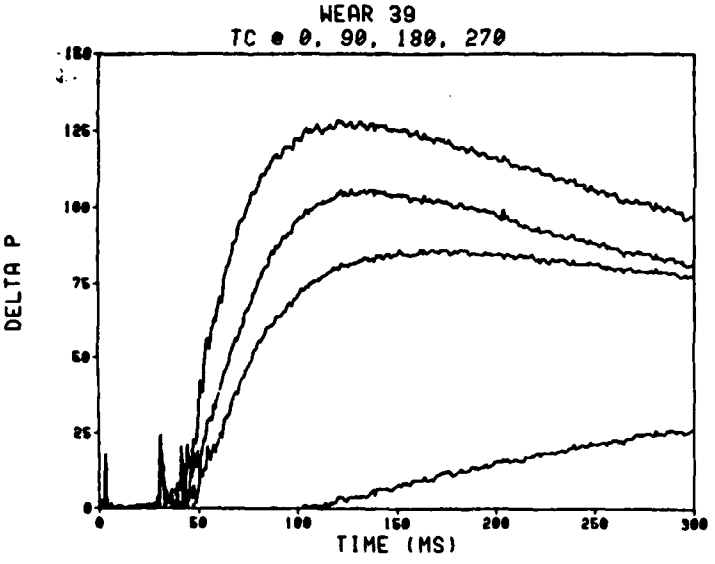

WEAR 38
BREECH & FORWARD PRESSURE
PRESSURE (MPA)
450
400
350
300
250
200
150
100
50
0
18
23
28
33
38
43
TIME (MS)

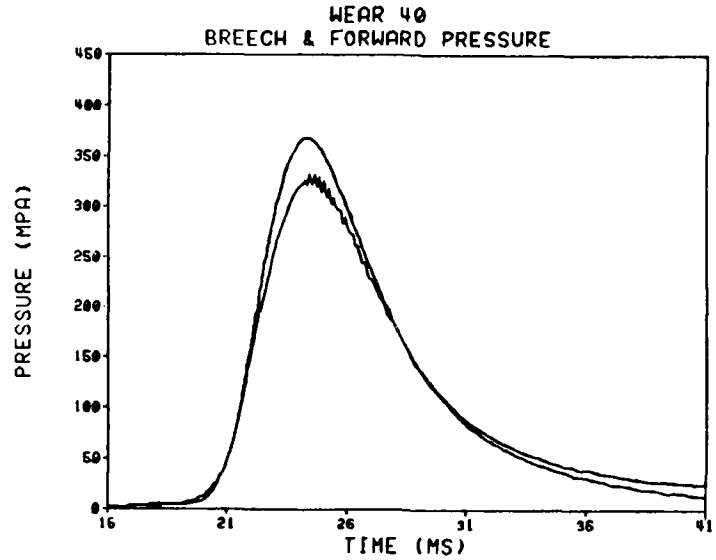

WEAR 38
DELTA P
PRESSURE (MPA)
100
75
50
25
0
-25
18
23
28
33
38
43
TIME (MS)

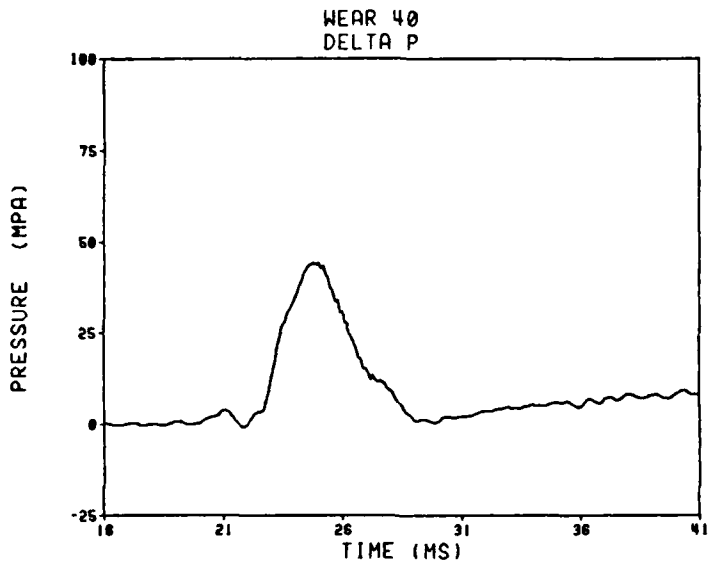

WEAR 38
TC @ 0, 90, 180, 270 DEG
DELTA TEMP (DEG C)
150
125
100
75
50
25
0
0
50
100
150
200
250
300
TIME (MS)

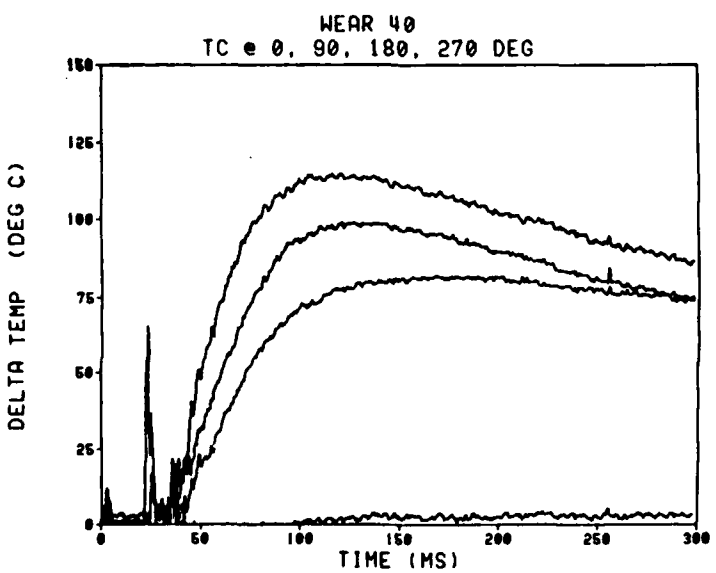

WEAR 39
BREECH & FORWARD PRESSURE
PRESSURE (MPA)
TIME (MS)

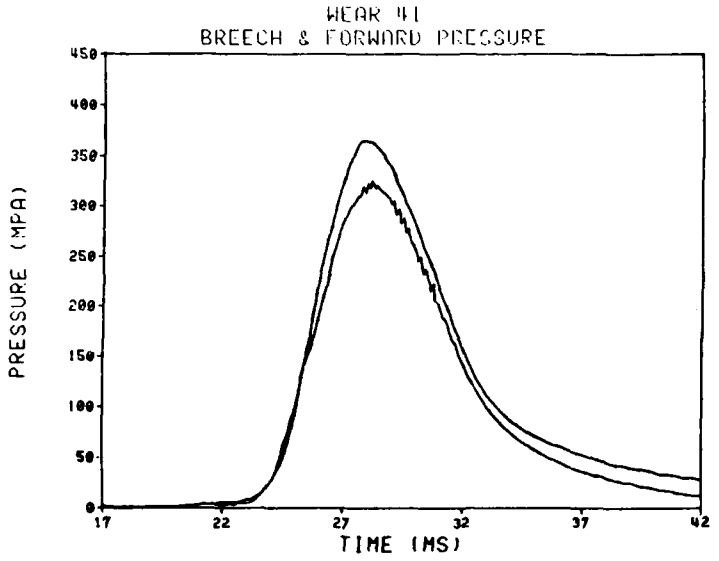

WEAR 39
DELTA P
PRESSURE (MPA)
TIME (MS)

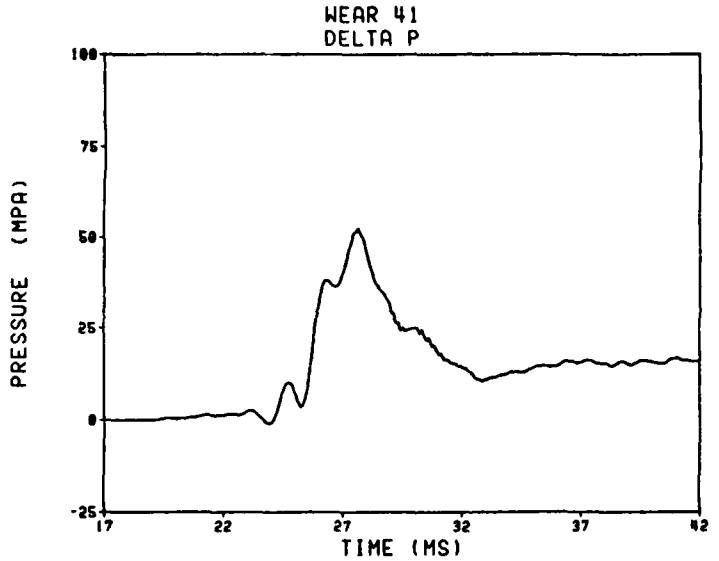

WEAR 39
TC @ 0, 90, 180, 270
DELTA P
TIME (MS)

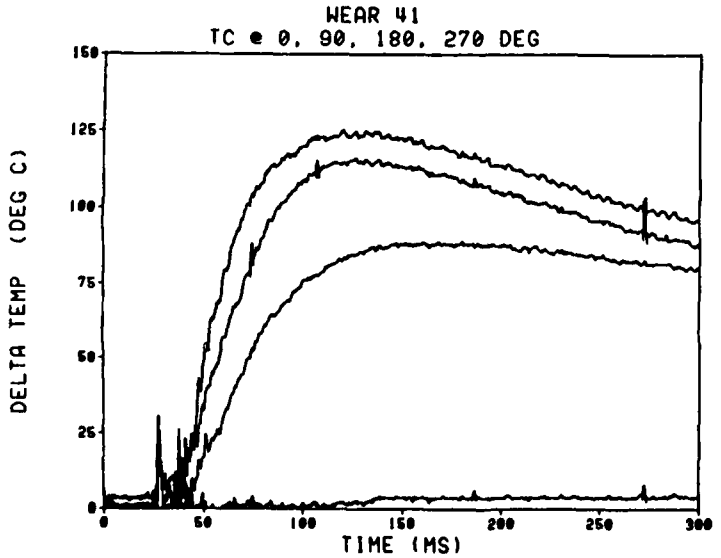

WEAR 40
BREECH & FORWARD PRESSURE
PRESSURE (MPA)
450
400
350
300
250
200
150
100
50
0
16
21
26
31
36
41
TIME (MS)

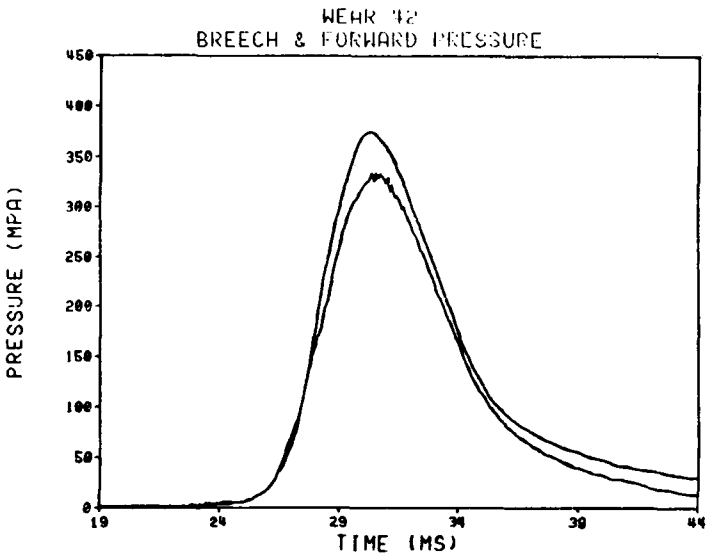

WEAR 40
DELTA P
PRESSURE (MPA)
100
75
50
25
0
-25
16
21
26
31
36
41
TIME (MS)

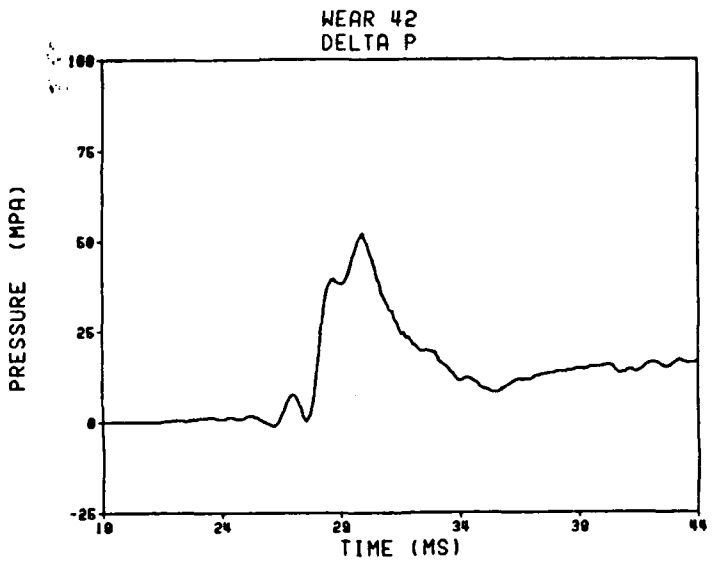

WEAR 40
TC @ 0, 90, 180, 270 DEG
DELTA TEMP (DEG C)
150
125
100
75
50
25
0
0
50
100
150
200
250
300
TIME (MS)

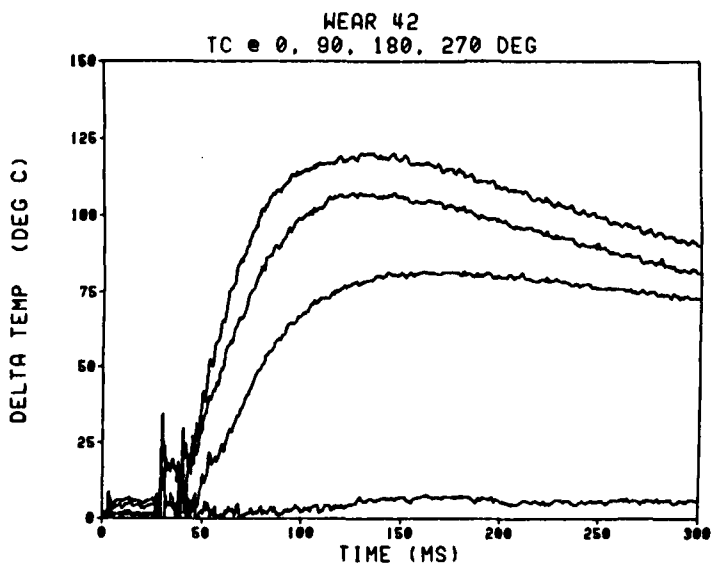

WEAR 41
BREECH & FORWARD PRESSURE
PRESSURE (MPA)
450
400
350
300
250
200
150
100
50
0
17
22
27
32
37
42
TIME (MS)

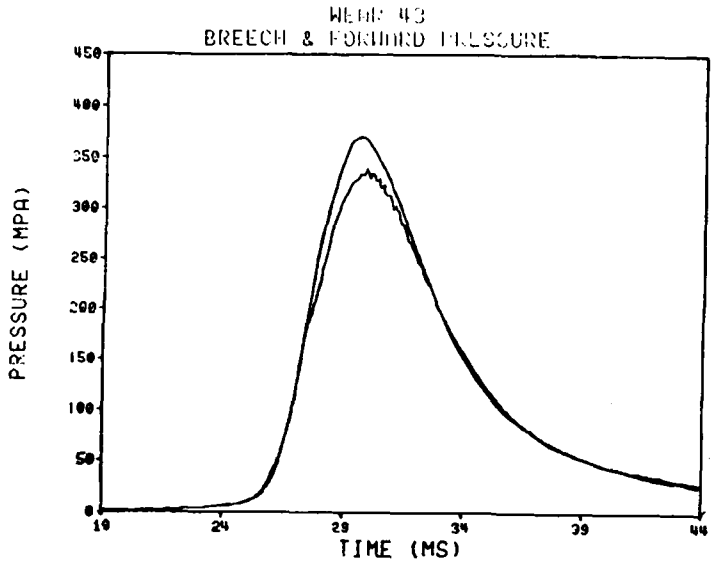

WEAR 41
DELTA P
PRESSURE (MPA)
100
75
50
25
0
-25
17
22
27
32
37
42
TIME (MS)

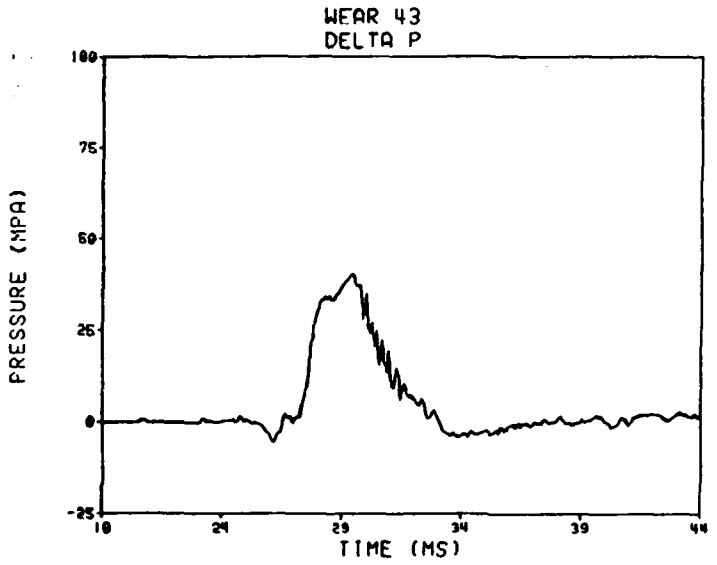

WEAR 41
TC @ 0, 90, 180, 270 DEG
DELTA TEMP (DEG C)
150
125
100
75
50
25
0
0
50
100
150
200
250
300
TIME (MS)

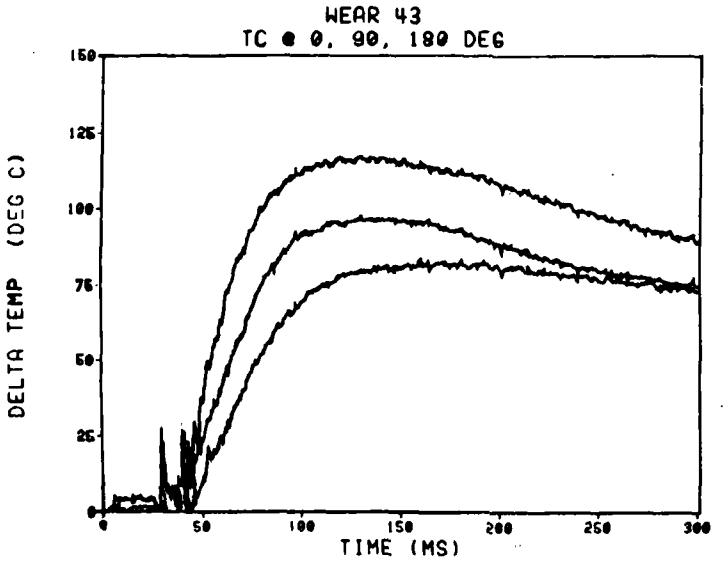

WEAR 42
BREECH & FORWARD PRESSURE
PRESSURE (MPA)
TIME (MS)

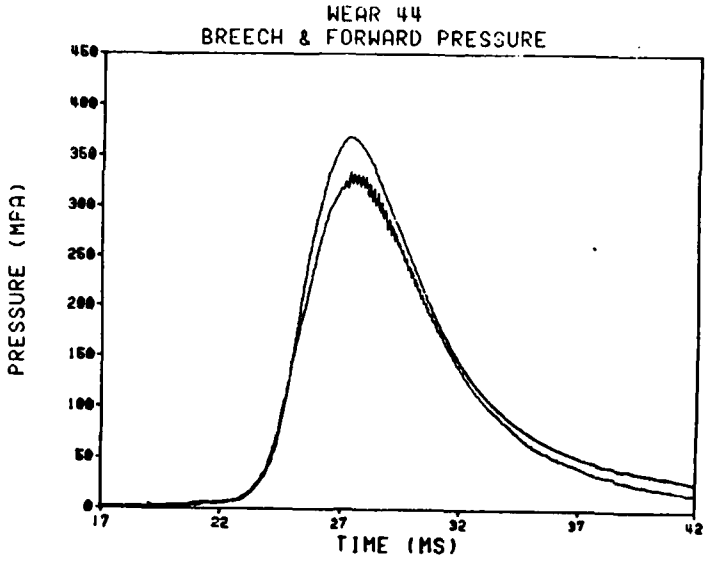

WEAR 42
DELTA P
PRESSURE (MPA)
TIME (MS)

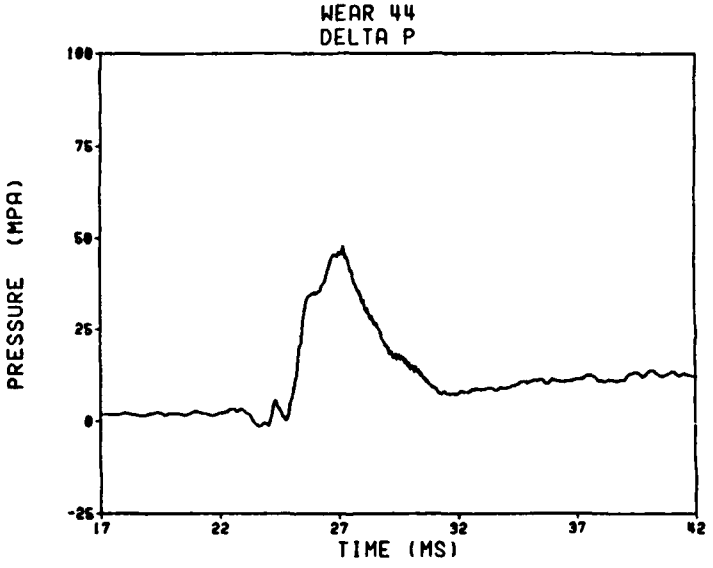

WEAR 42
TC @ 0, 90, 180, 270 DEG
DELTA TEMP (DEG C)
TIME (MS)

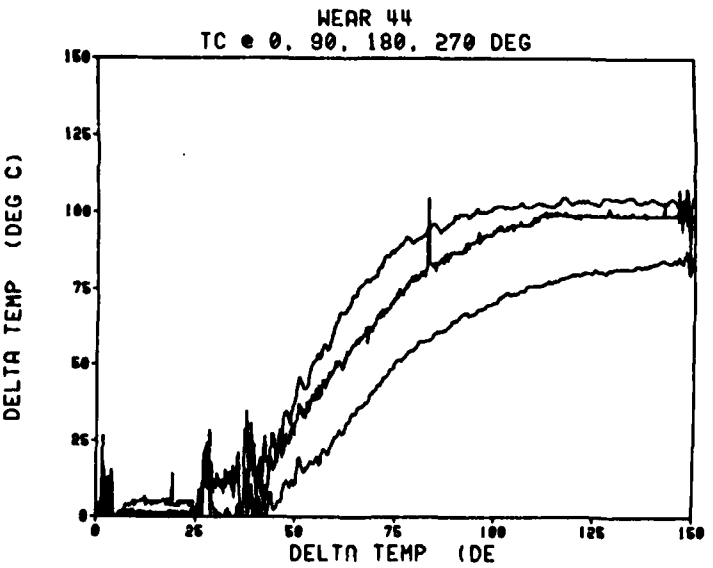

WEAR 43
BREECH & FORWARD PRESSURE
PRESSURE (MPA)
TIME (MS)

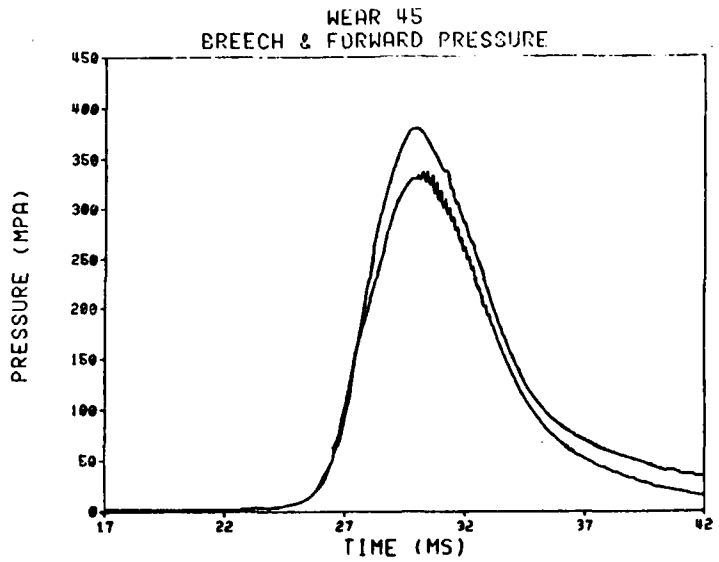

WEAR 43
DELTA P
PRESSURE (MPA)
TIME (MS)

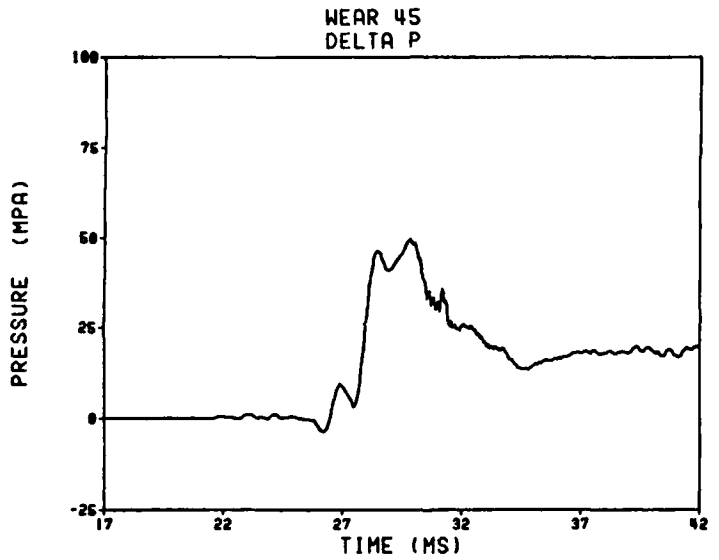

WEAR 43
TC @ 0, 90, 180 DEG
DELTA TEMP (DEG C)
TIME (MS)

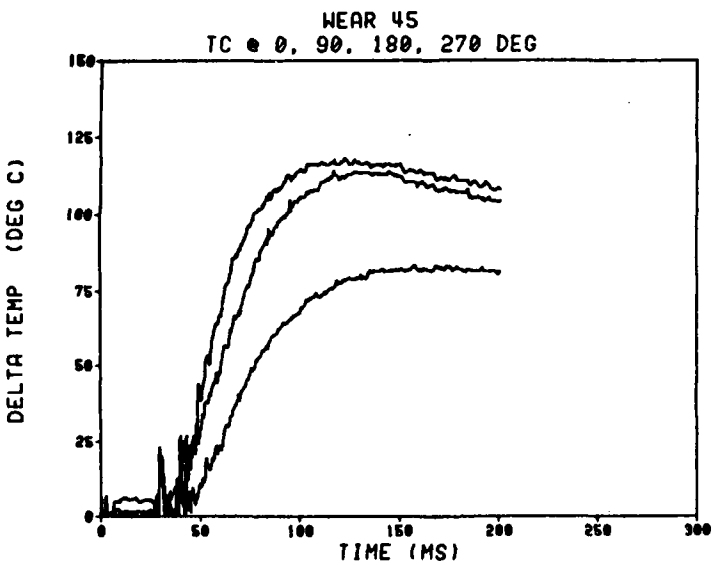

WEAR 44
BREECH & FORWARD PRESSURE
PRESSURE (MPA)
450
400
350
300
250
200
150
100
50
0
17
22
27
32
37
42
TIME (MS)

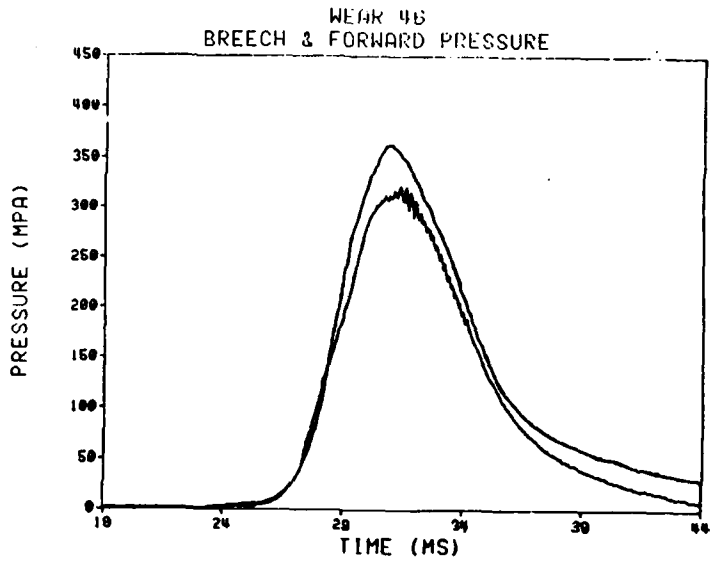

WEAR 44
DELTA P
PRESSURE (MPA)
100
75
50
25
0
-25
17
22
27
32
37
42
TIME (MS)

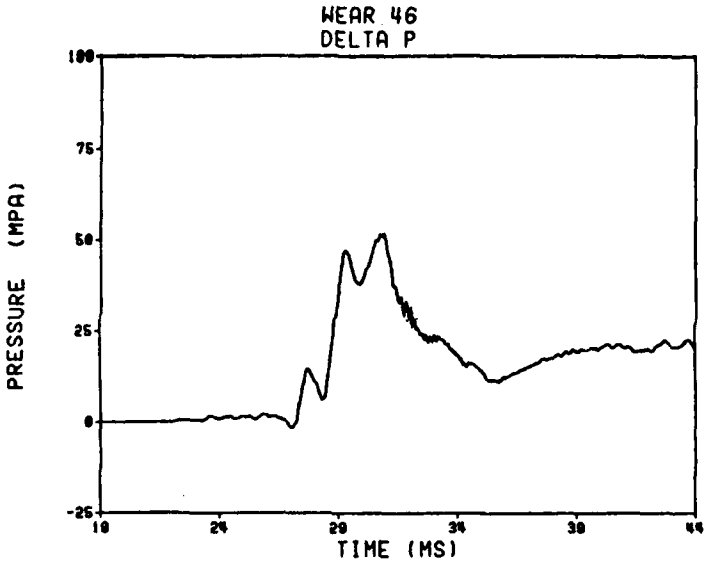

WEAR 44
TC @ 0, 90, 180, 270 DEG
DELTA TEMP (DEG C)
150
125
100
75
50
25
0
0
25
50
75
100
125
150
DELTA TEMP (DE

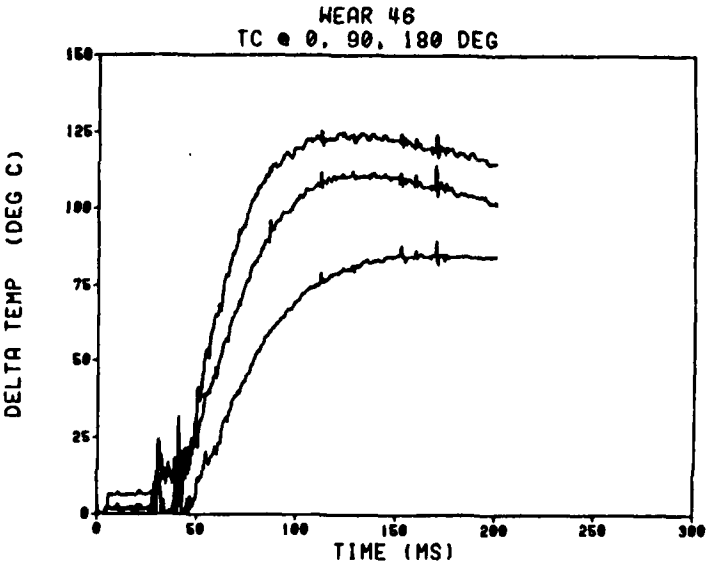

WEAR 45
BREECH & FORWARD PRESSURE
PRESSURE (MPA)
450
400
350
300
250
200
150
100
50
0
17
22
27
32
37
42
TIME (MS)

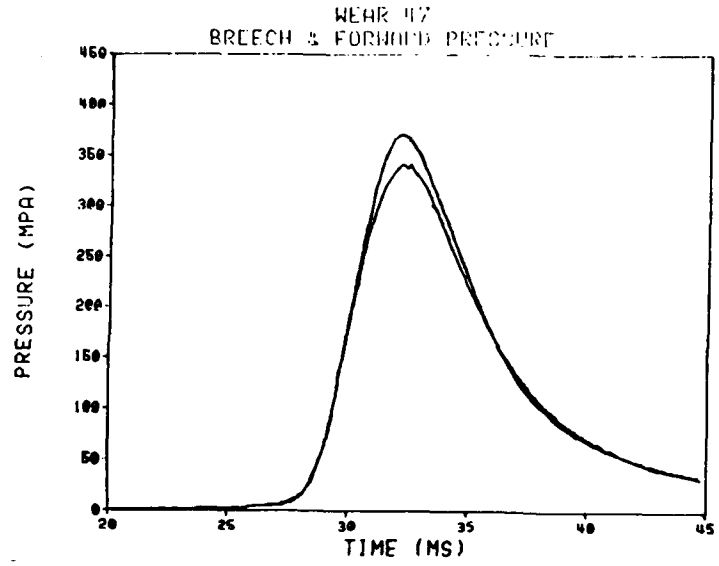

WEAR 45
DELTA P
PRESSURE (MPA)
100
75
50
25
0
-25
17
22
27
32
37
42
TIME (MS)

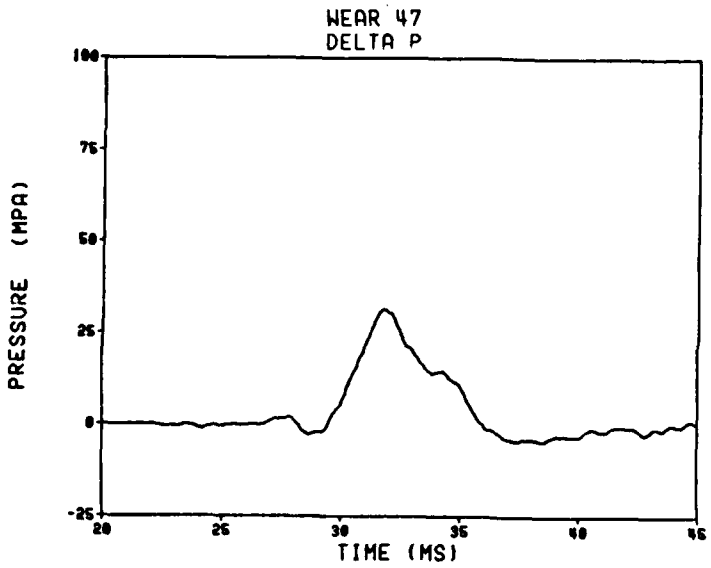

WEAR 45
TC @ 0, 90, 180, 270 DEG
DELTA TEMP (DEG C)
150
125
100
75
50
25
0
0
50
100
150
200
250
300
TIME (MS)

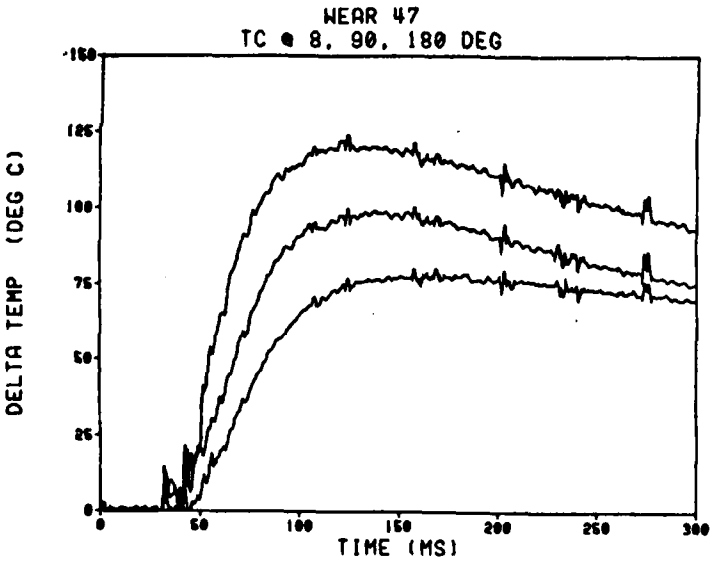

WEAR 46
BREECH & FORWARD PRESSURE
PRESSURE (MPA)
TIME (MS)

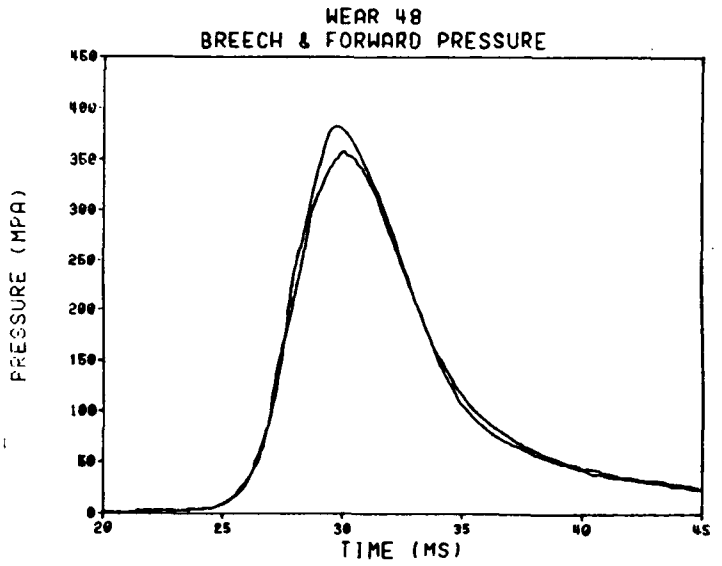

WEAR 46
DELTA P
PRESSURE (MPA)
TIME (MS)

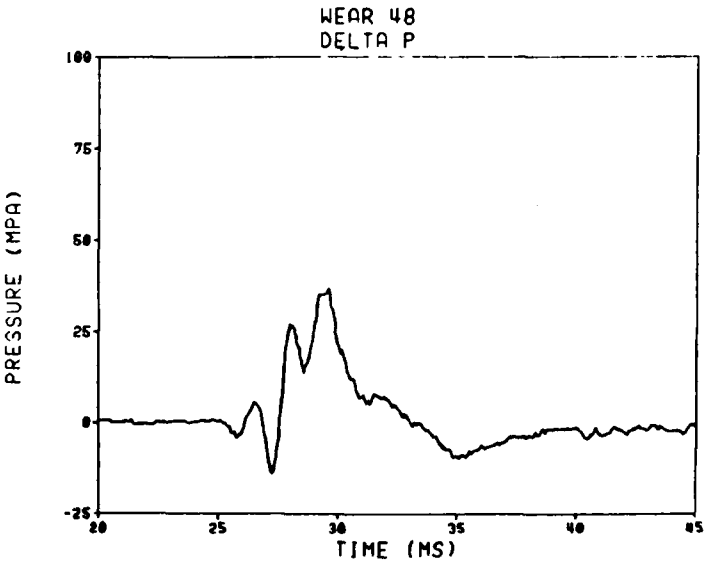

WEAR 46
TC @ 0, 90, 180 DEG
DELTA TEMP (DEG C)
TIME (MS)

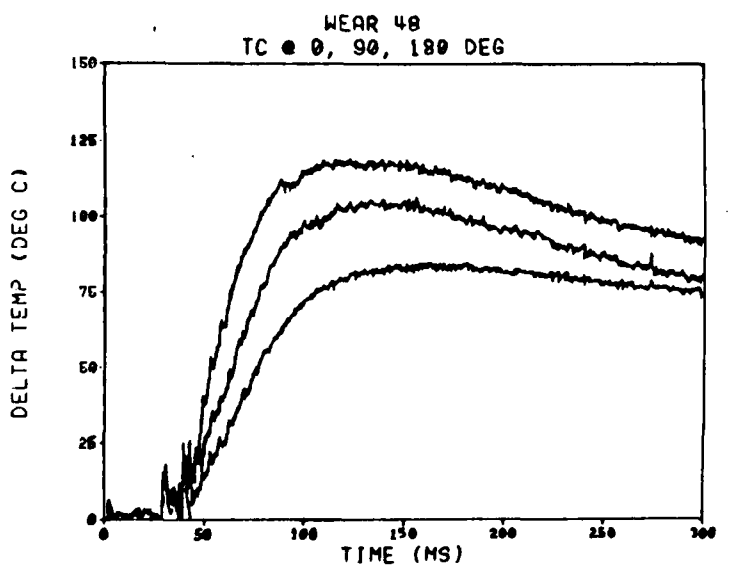

WEAR 47
BREECH & FORWARD PRESSURE
PRESSURE (MPA)
TIME (MS)

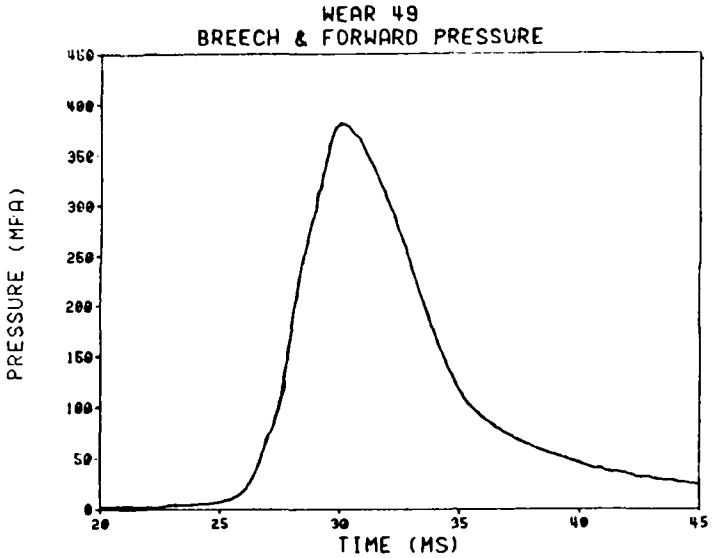

WEAR 47
DELTA P
PRESSURE (MPA)
TIME (MS)


WEAR 47
TC @ 8, 90, 180 DEG
DELTA TEMP (DEG C)
TIME (MS)

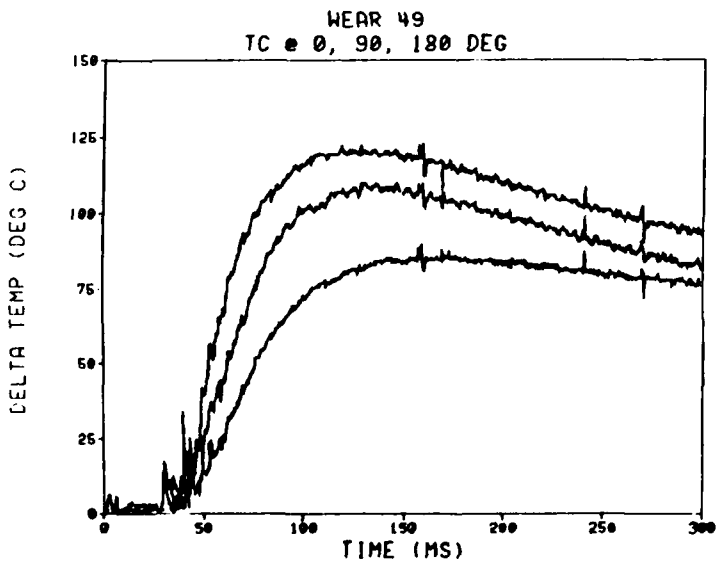

WEAR 48
BREECH & FORWARD PRESSURE
PRESSURE (MPA)
TIME (MS)

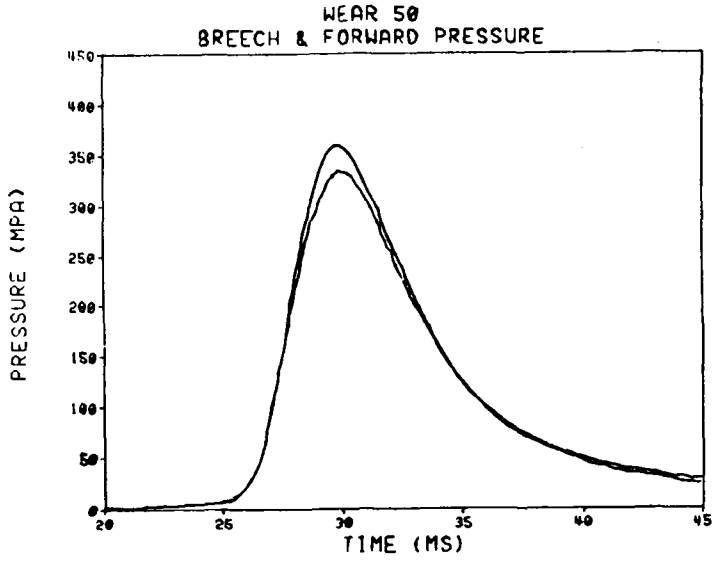

WEAR 48
DELTA P
PRESSURE (MPA)
TIME (MS)

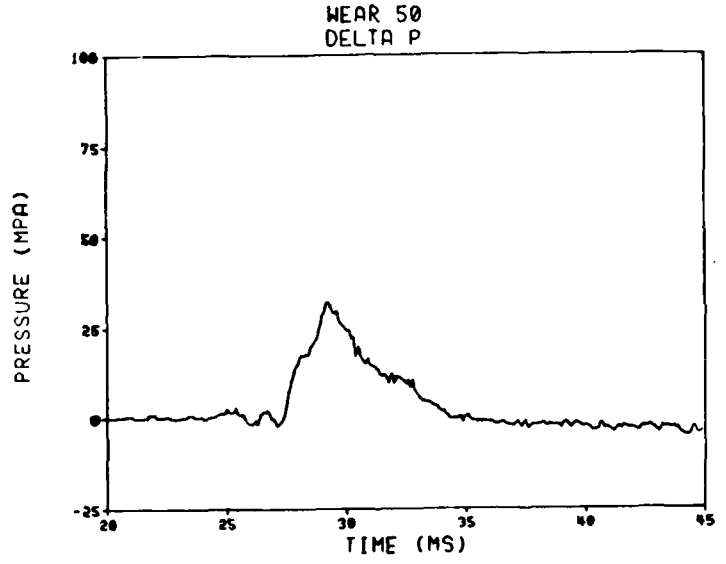

WEAR 48
TC @ 0, 90, 180 DEG
DELTA TEMP (DEG C)
TIME (MS)

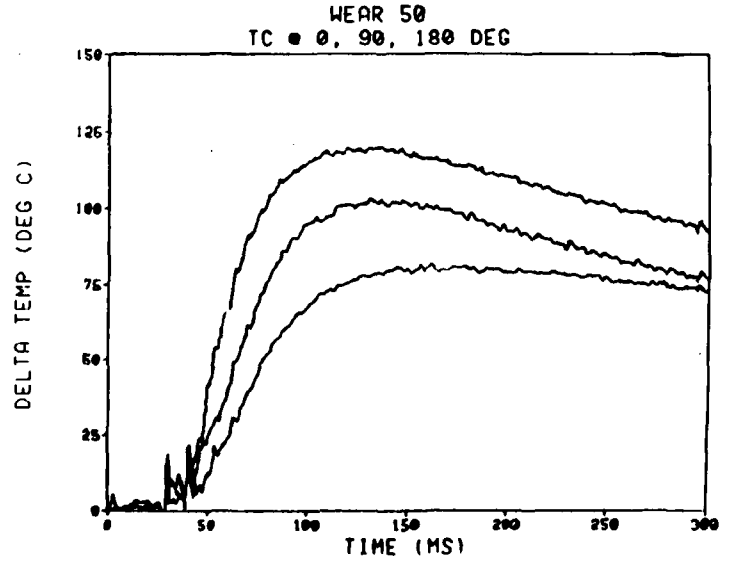

WEAR 49
BREECH & FORWARD PRESSURE
PRESSURE (MFA)
400
350
300
250
200
150
100
50
0
20
25
30
35
40
45
TIME (MS)

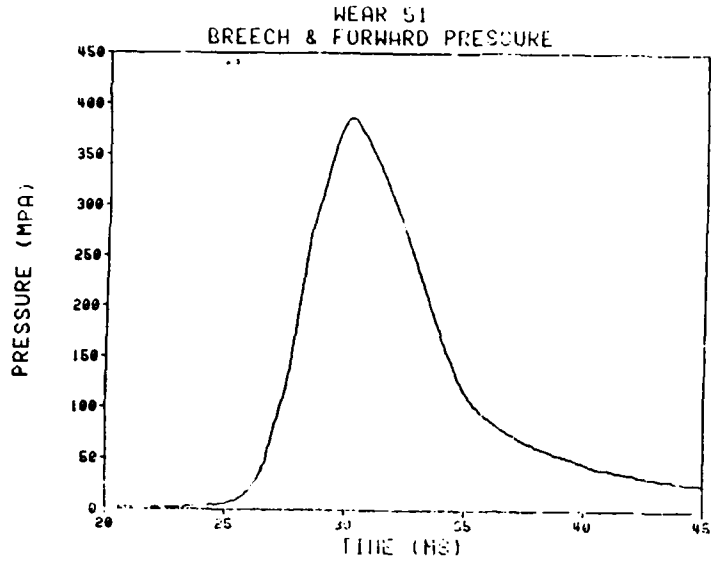
DATA LOST


WEAR 49
TC @ 0, 90, 180 DEG
DELTA TEMP (DEG C)
150
125
100
75
50
25
0
0
50
100
150
200
250
300
TIME (MS)

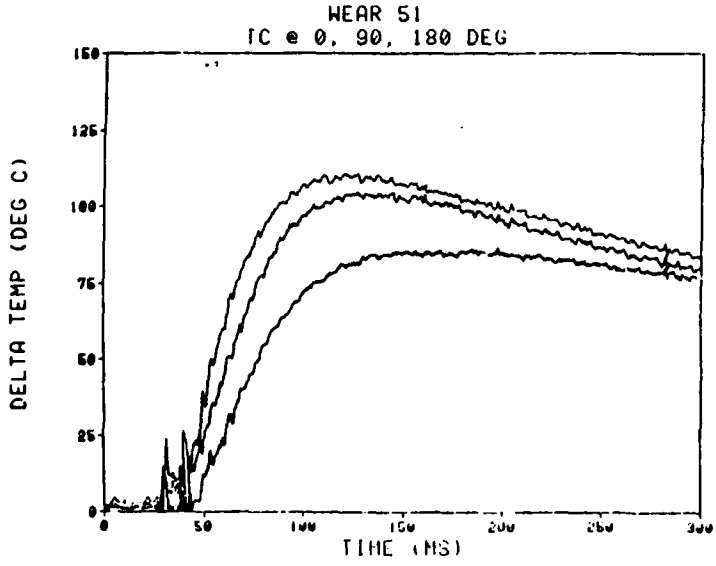

WEAR 50
BREECH & FORWARD PRESSURE
PRESSURE (MPA)
TIME (MS)

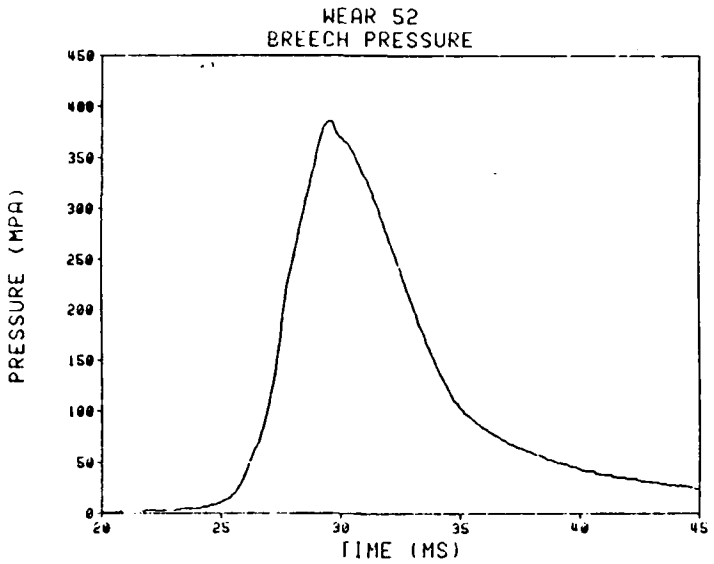

WEAR 50
DELTA P
PRESSURE (MPA)
TIME (MS)


WEAR 50
TC @ 0, 90, 180 DEG
DELTA TEMP (DEG C)
TIME (MS)

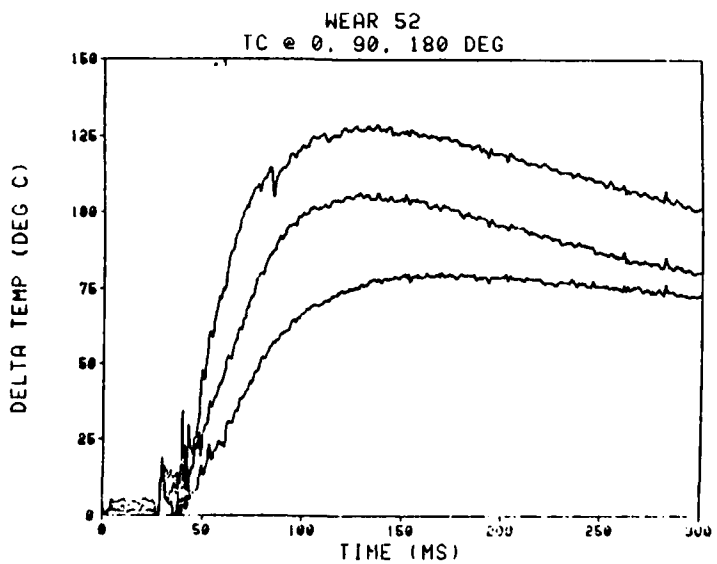

WEAR 51
BREECH & FORWARD PRESSURE
PRESSURE (MPA)
TIME (MS)

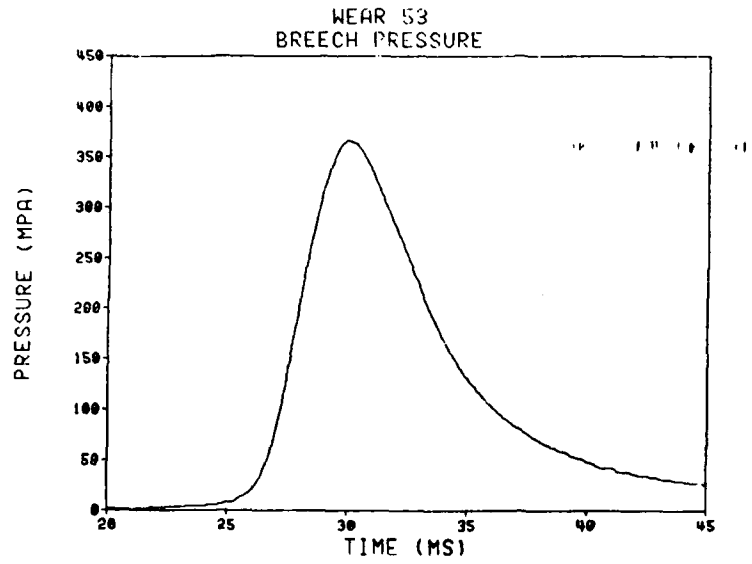
DATA LOST


WEAR 51
TC @ 0, 90, 180 DEG
DELTA TEMP (DEG C)
TIME (MS)

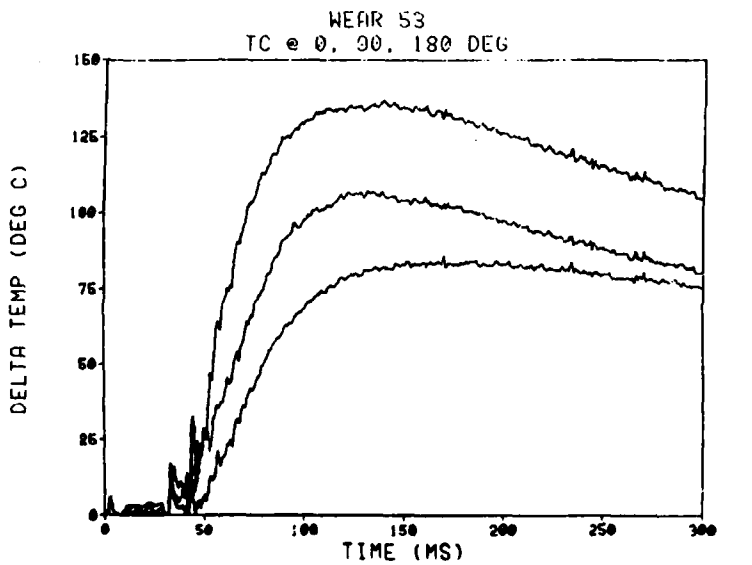

WEAR 52
BREECH PRESSURE
PRESSURE (MPA)
TIME (MS)

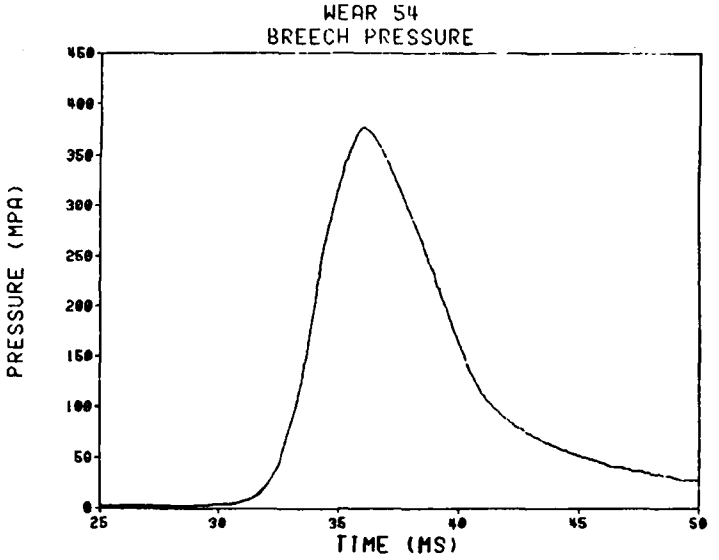
DATA LOST


WEAR 52
TC @ 0, 90, 180 DEG
DELTA TEMP (DEG C)
TIME (MS)

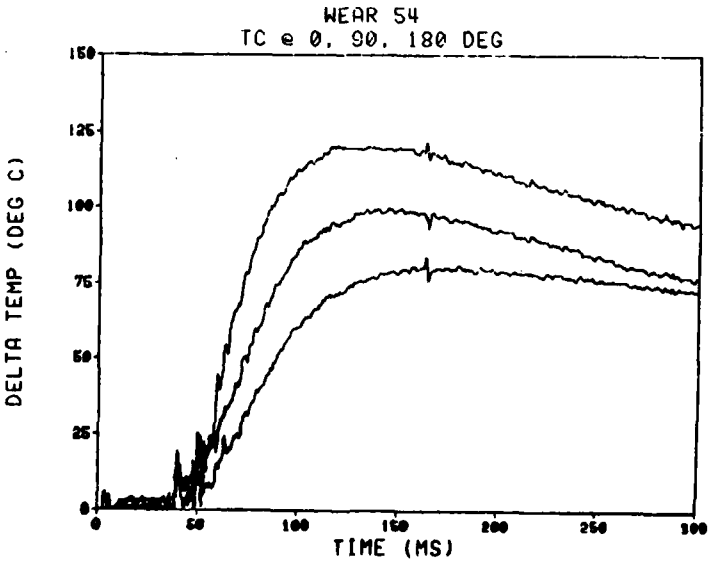

WEAR 53
BREECH PRESSURE
PRESSURE (MPA)
TIME (MS)

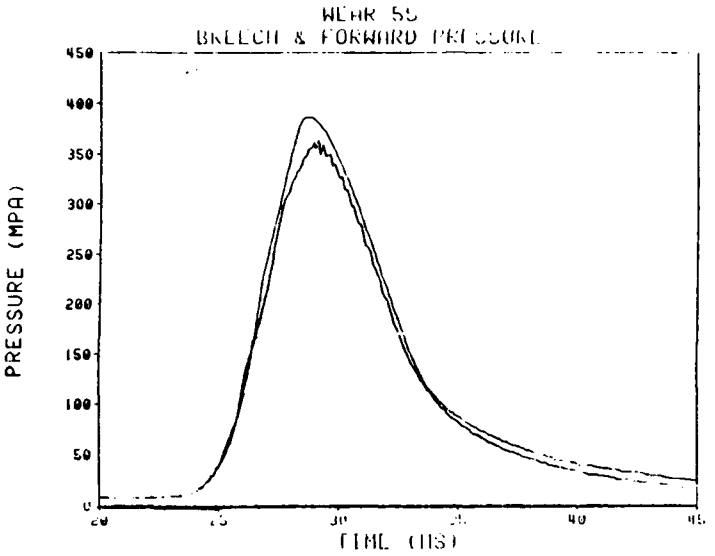
DATA LOST

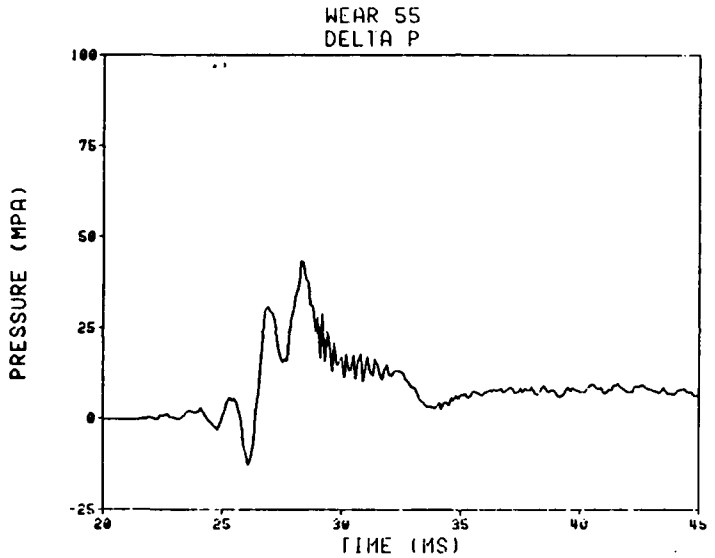

WEAR 53
TC @ 0, 90, 180 DEG
DELTA TEMP (DEG C)
TIME (MS)

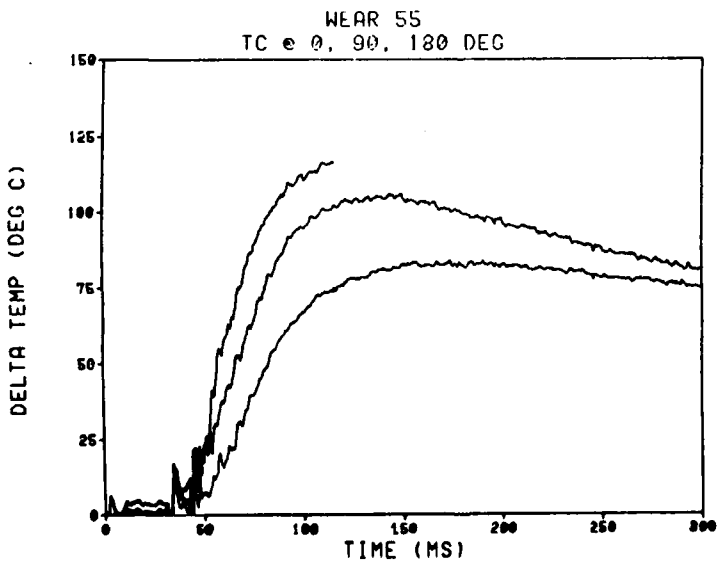

WEAR 54
BREECH PRESSURE
PRESSURE (MPA)
450
400
350
300
250
200
150
100
50
0
25
30
35
40
45
50
TIME (MS)

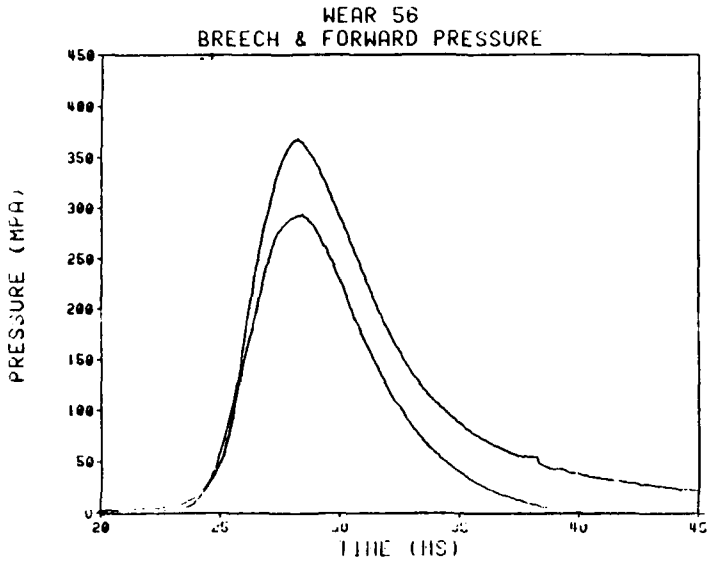
DATA LOST

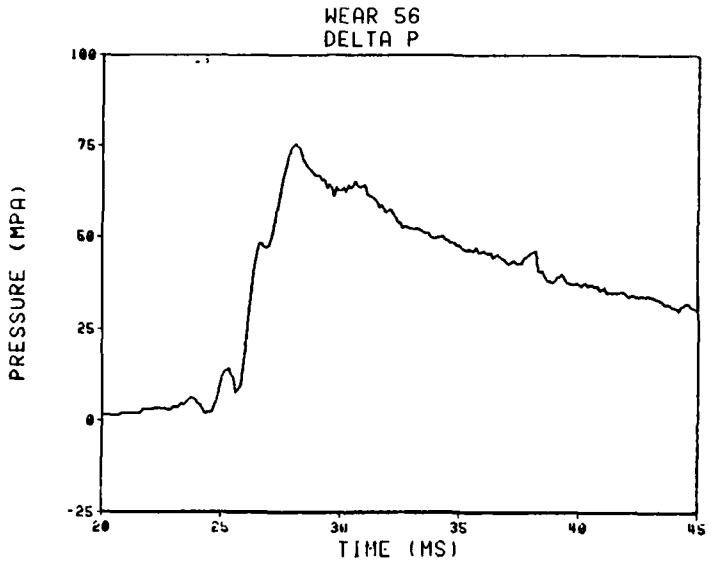

WEAR 54
TC @ 0, 90, 180 DEG
DELTA TEMP (DEG C)
150
125
100
75
50
25
0
0
50
100
150
200
250
300
TIME (MS)

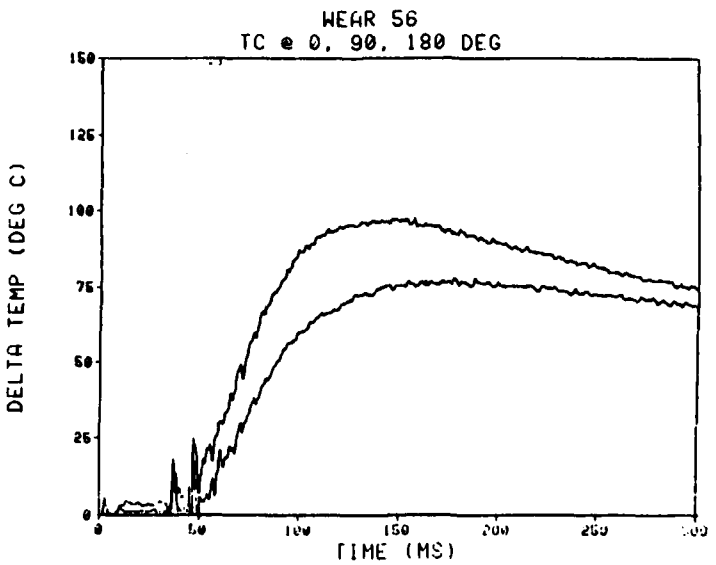

WEAR 55
BREECH & FORWARD PRESSURE
PRESSURE (MPA)
TIME (MS)

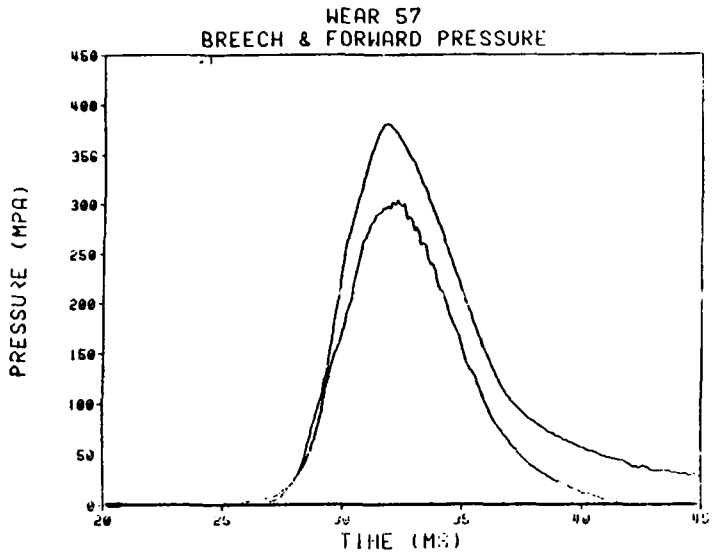

WEAR 55
DELTA P
PRESSURE (MPA)
TIME (MS)

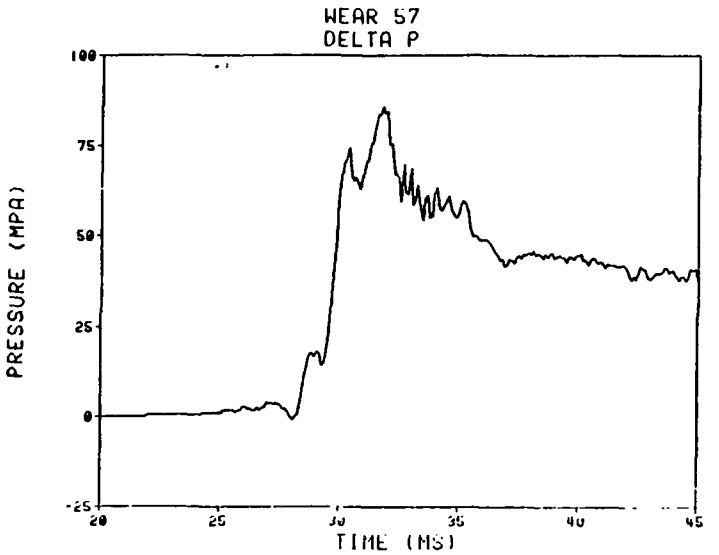

WEAR 55
TC @ 0, 90, 180 DEG
DELTA TEMP (DEG C)
TIME (MS)

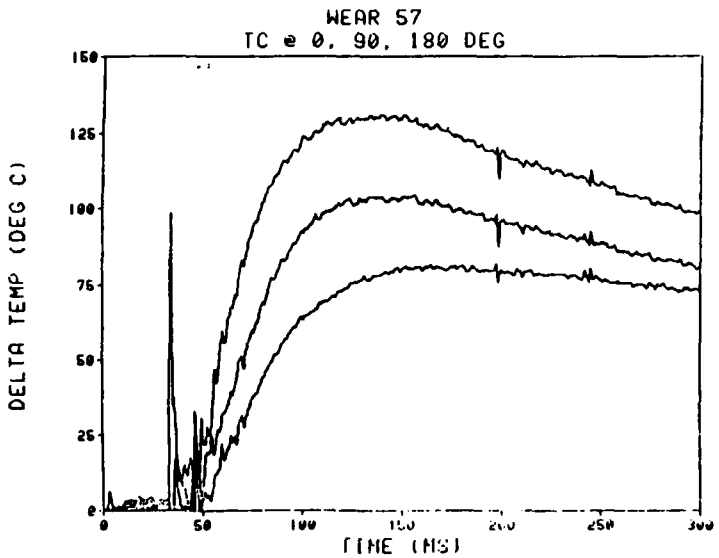

WEAR 56
BREECH & FORWARD PRESSURE
PRESSURE (MPA)
TIME (MS)

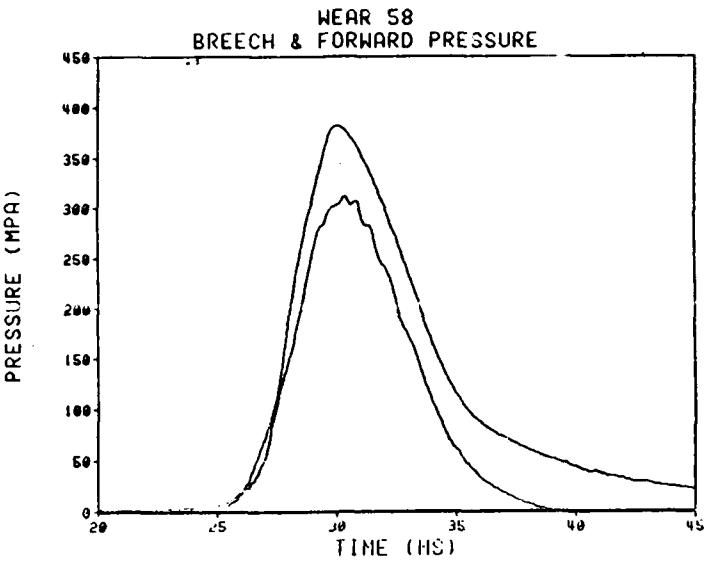

WEAR 56
DELTA P
PRESSURE (MPA)
TIME (MS)

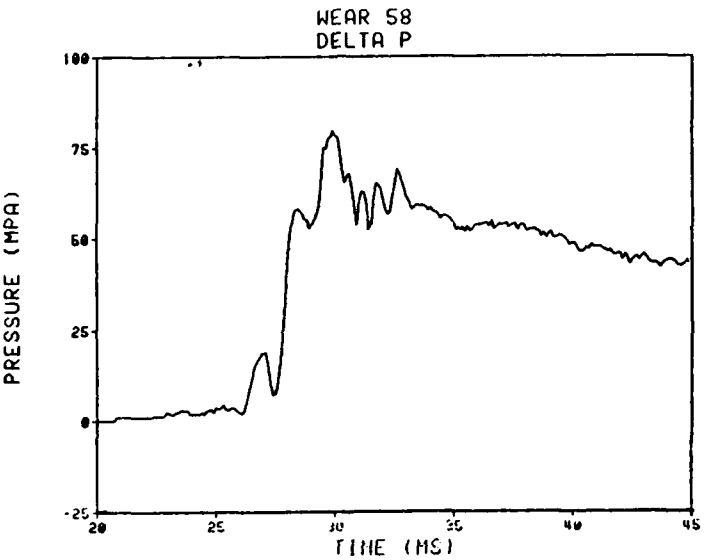

WEAR 56
TC @ 0, 90, 180 DEG
DELTA TEMP (DEG C)
TIME (MS)

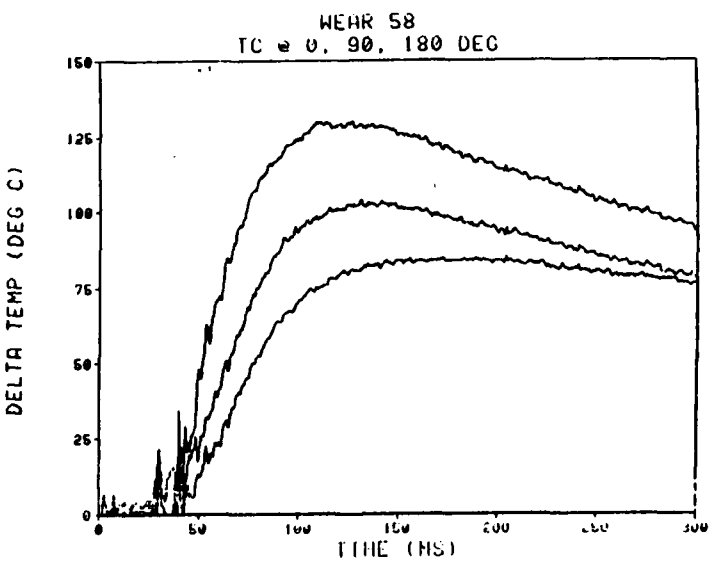

WEAR 57
BREECH & FORWARD PRESSURE
PRESSURE (MPA)
TIME (MS)

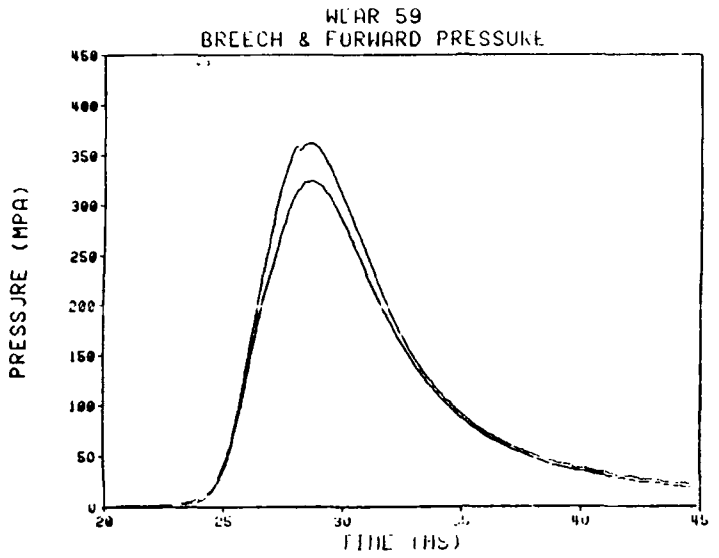

WEAR 57
DELTA P
PRESSURE (MPA)
TIME (MS)

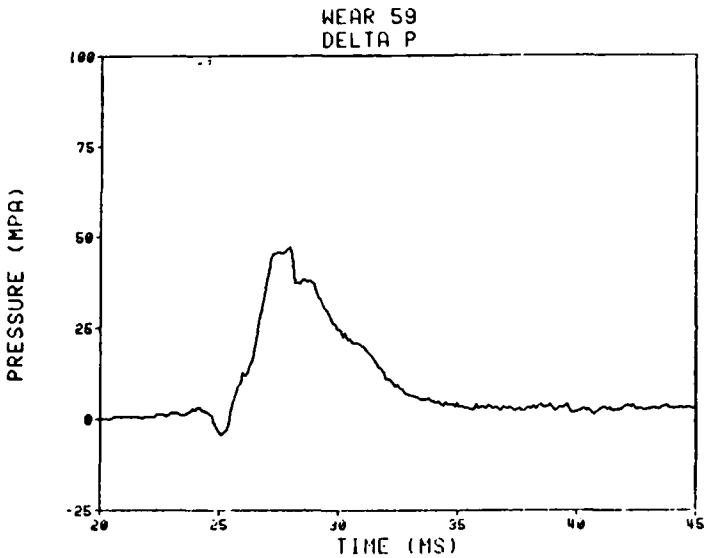

WEAR 57
TC @ 0, 90, 180 DEG
DELTA TEMP (DEG C)
TIME (MS)

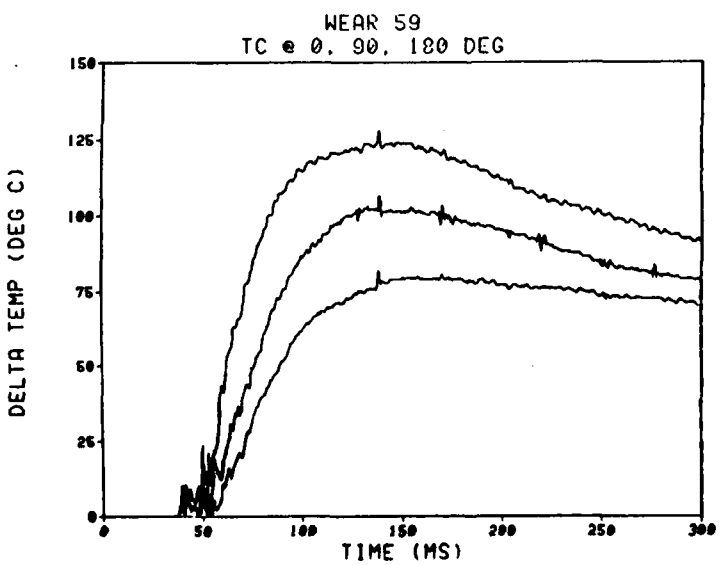

WEAR 58
BREECH & FORWARD PRESSURE
PRESSURE (MPA)
TIME (MS)

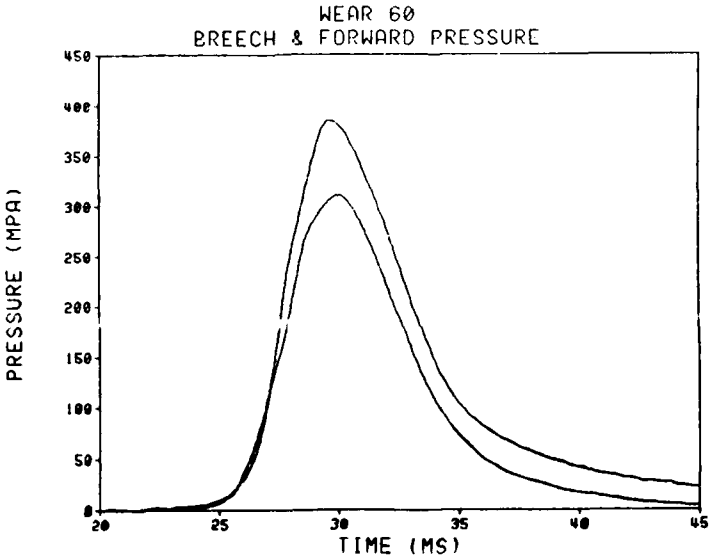

WEAR 58
DELTA P
PRESSURE (MPA)
TIME (MS)

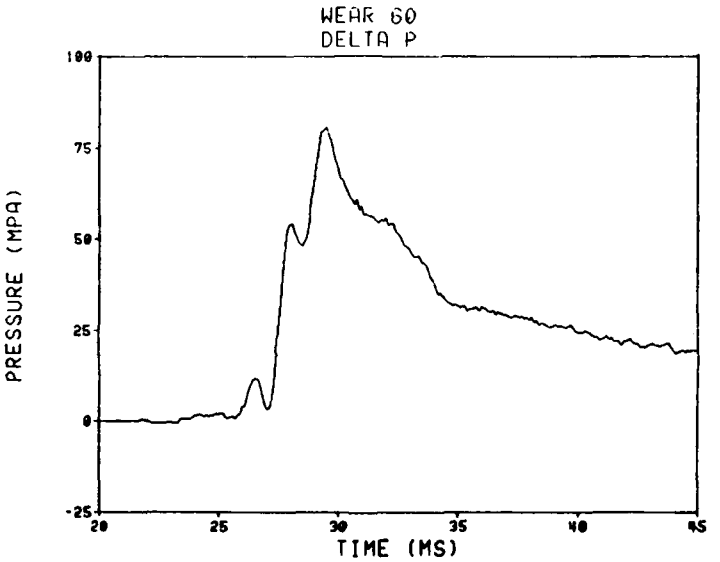

WEAR 58
TC @ 0, 90, 180 DEG
DELTA TEMP (DEG C)
TIME (MS)

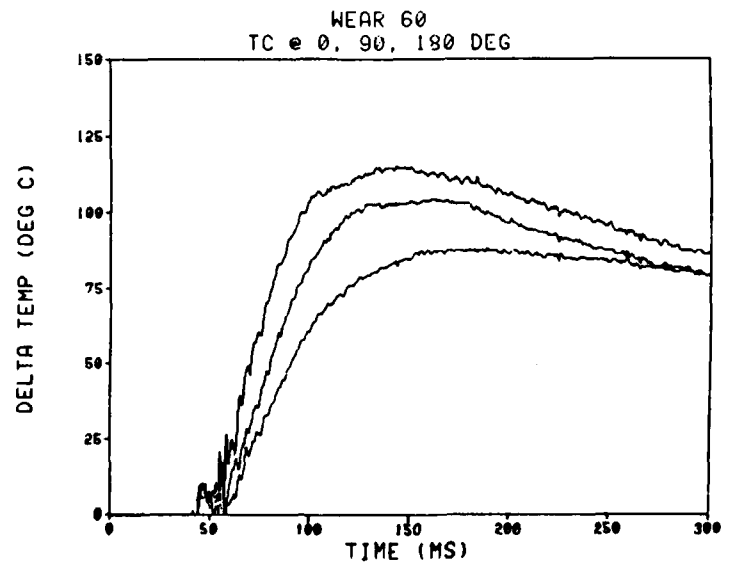

WEAR 59
BREECH & FORWARD PRESSURE
PRESSURE (MPA)
TIME (MS)

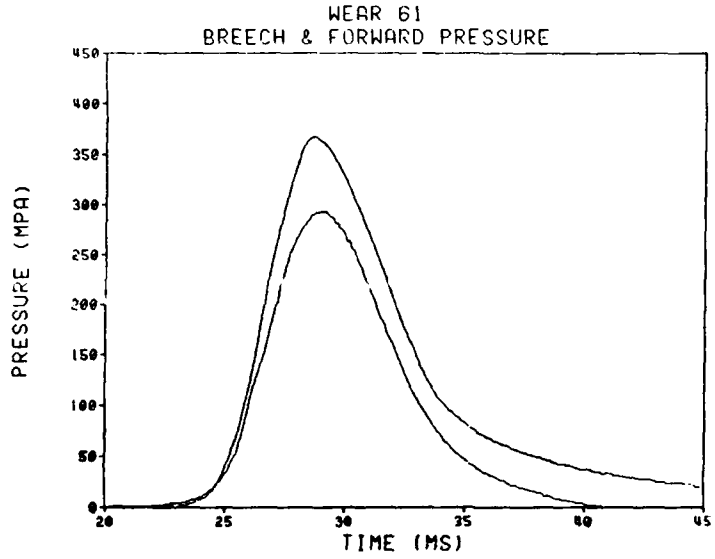

WEAR 59
DELTA P
PRESSURE (MPA)
TIME (MS)

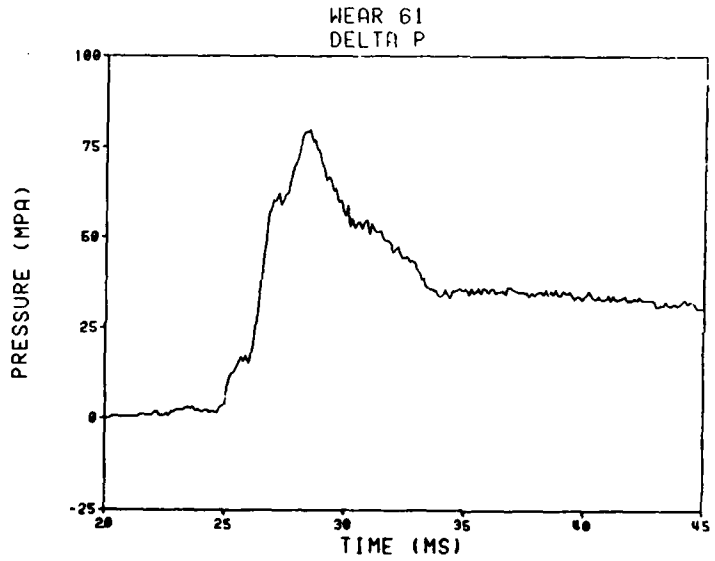

WEAR 59
TC @ 0, 90, 180 DEG
DELTA TEMP (DEG C)
TIME (MS)

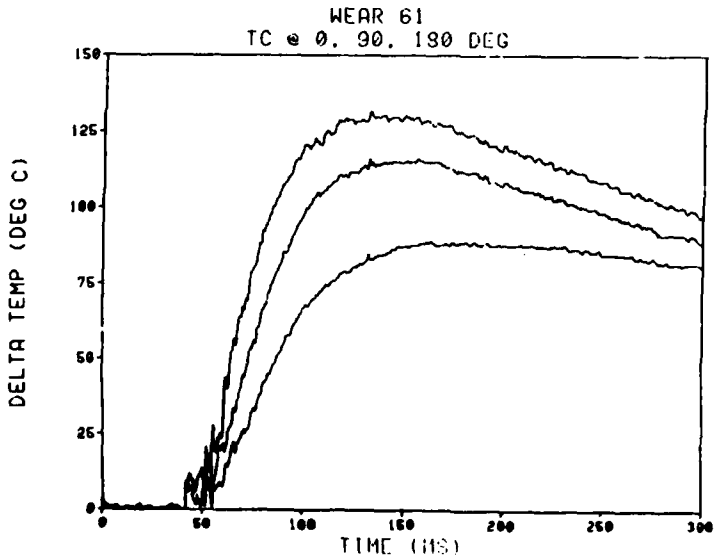

WEAR 60
BREECH & FORWARD PRESSURE
PRESSURE (MPA)
TIME (MS)

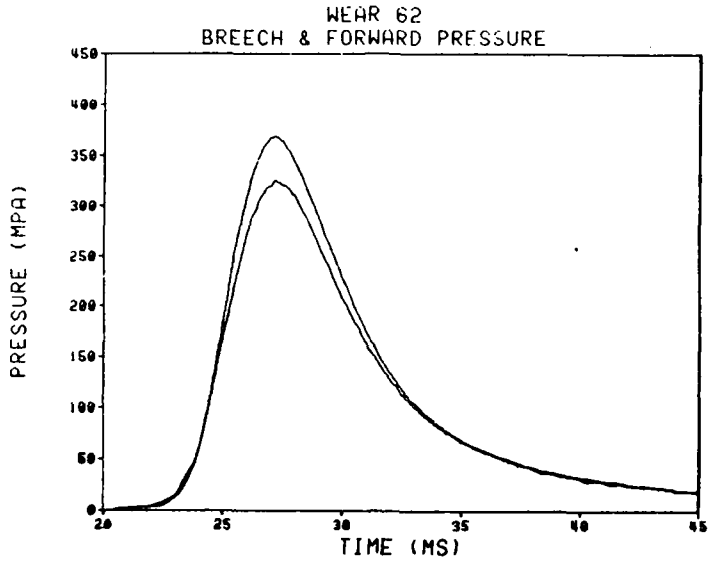

WEAR 60
DELTA P
PRESSURE (MPA)
TIME (MS)

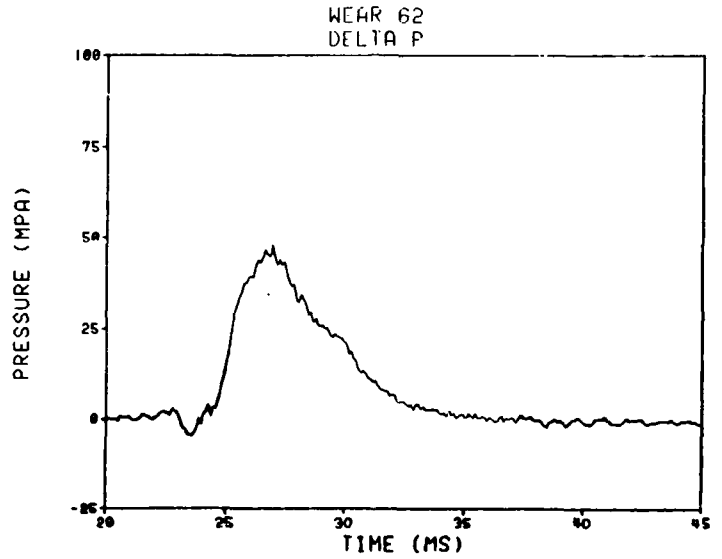

WEAR 60
TC @ 0, 90, 180 DEG
DELTA TEMP (DEG C)
TIME (MS)

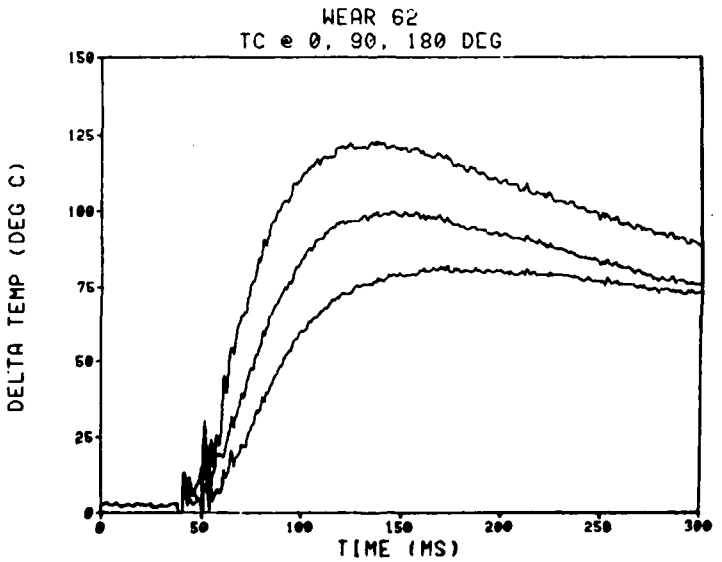

WEAR 61
BREECH & FORWARD PRESSURE
PRESSURE (MPA)
TIME (MS)

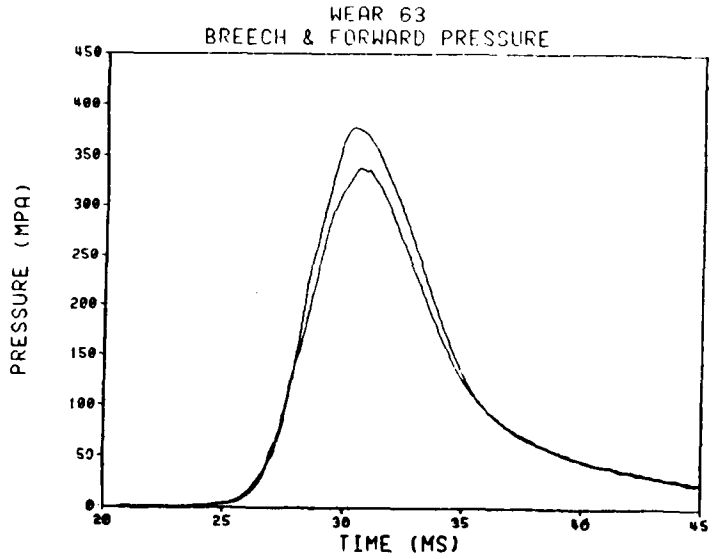

WEAR 61
DELTA P
PRESSURE (MPA)
TIME (MS)

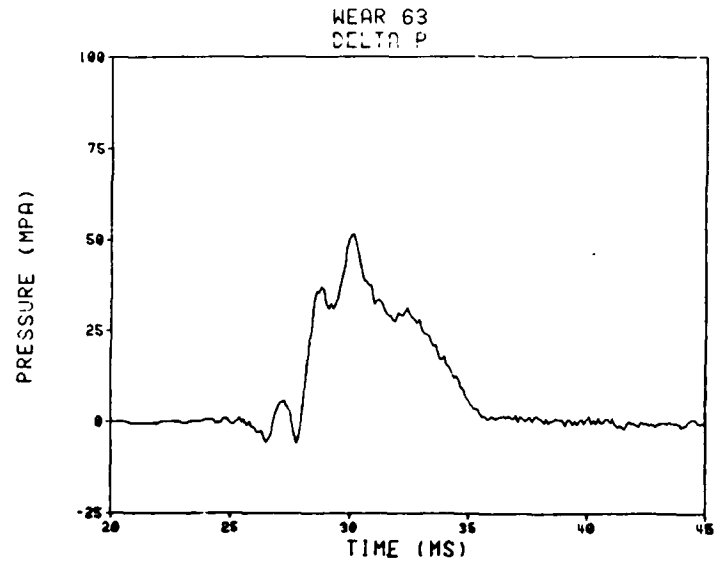

WEAR 61
TC @ 0, 90, 180 DEG
DELTA TEMP (DEG C)
TIME (MS)

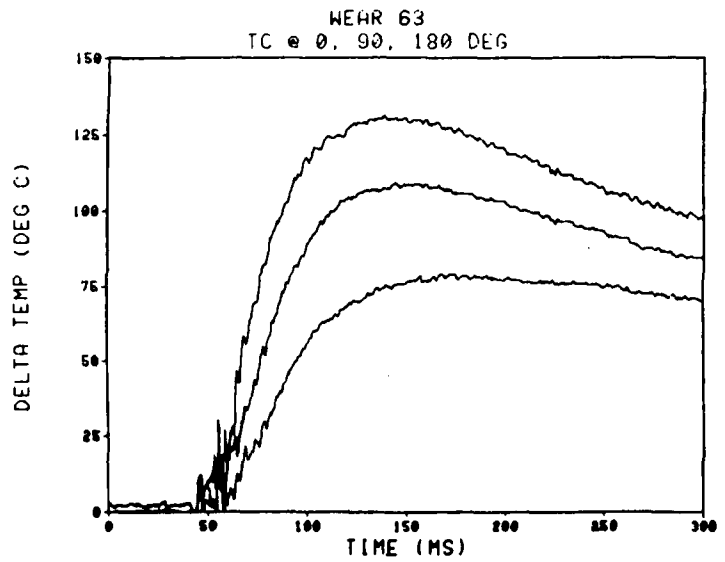

WEAR 62
BREECH & FORWARD PRESSURE
PRESSURE (MPA)
TIME (MS)

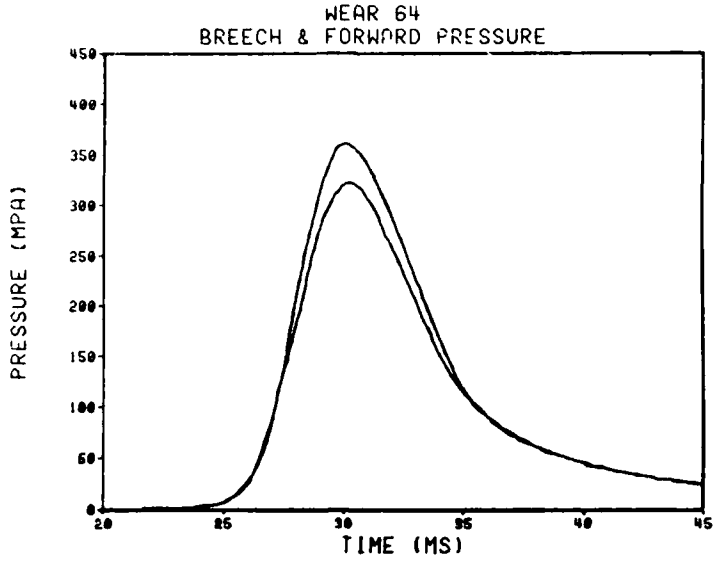

WEAR 62
DELTA P
PRESSURE (MPA)
TIME (MS)

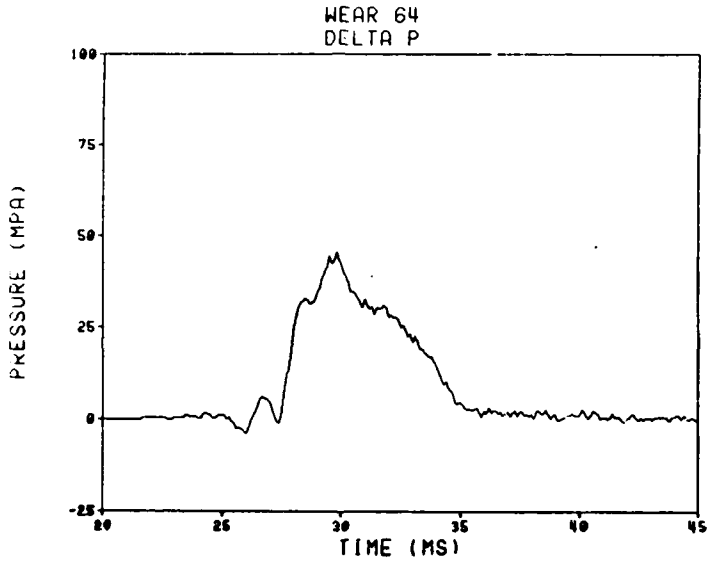

WEAR 62
TC @ 0, 90, 180 DEG
DELTA TEMP (DEG C)
TIME (MS)

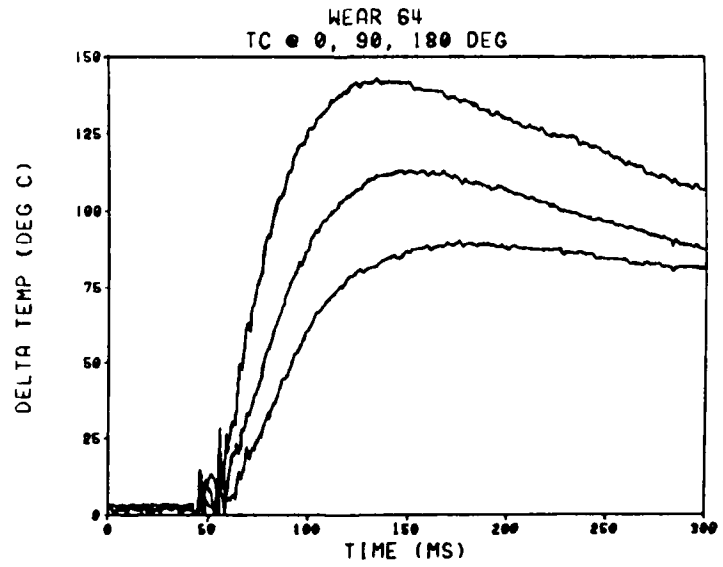

WEAR 63
BREECH & FORWARD PRESSURE
PRESSURE (MPA)
TIME (MS)

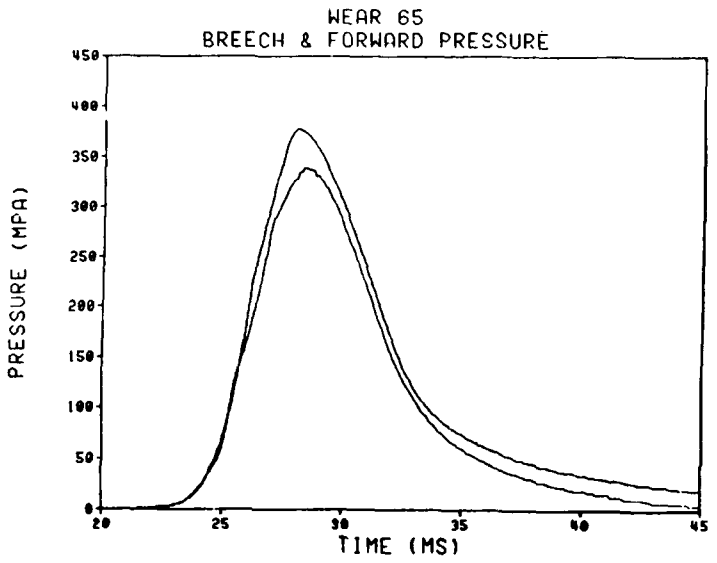

WEAR 63
DELTA P
PRESSURE (MPA)
TIME (MS)

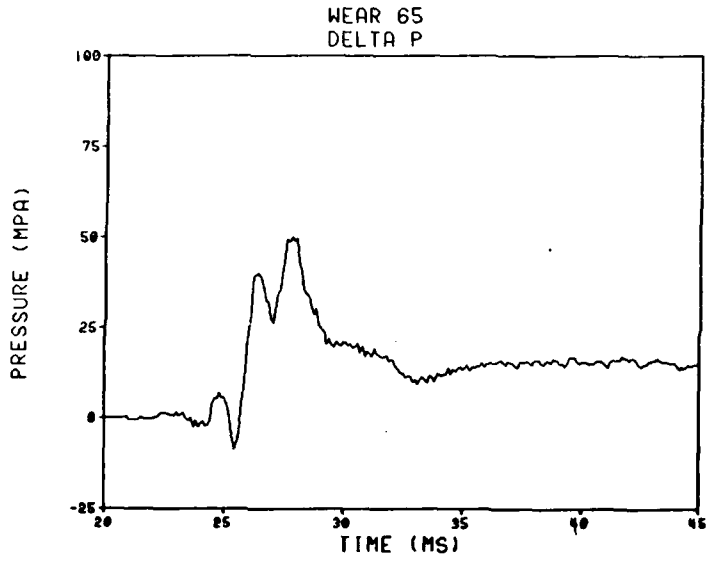

WEAR 63
TC @ 0, 90, 180 DEG
DELTA TEMP (DEG C)
TIME (MS)

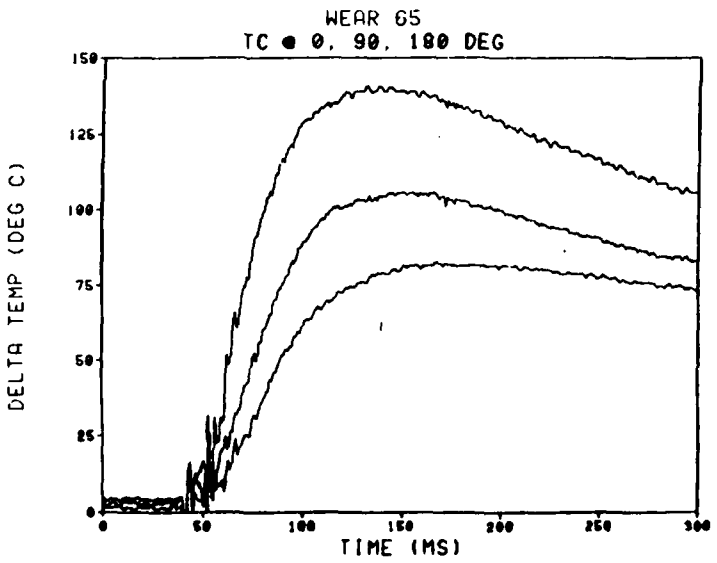

WEAR 64
BREECH & FORWARD PRESSURE
PRESSURE (MPA)
450
400
350
300
250
200
150
100
50
0
20
25
30
35
40
45
TIME (MS)

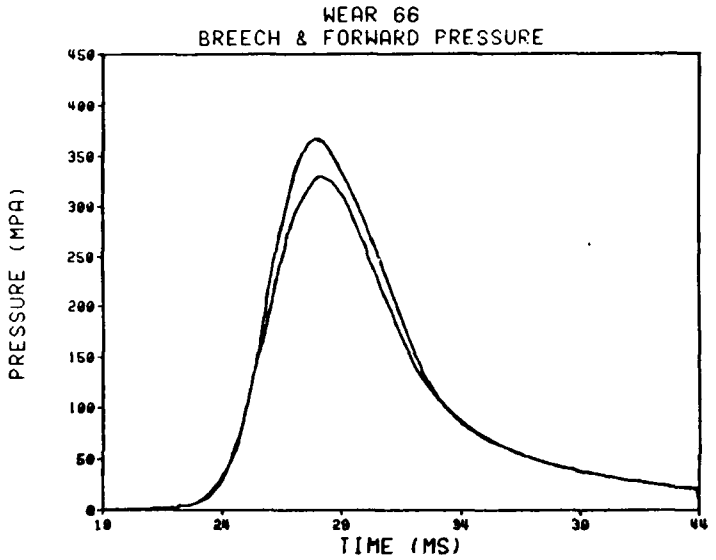

WEAR 64
DELTA P
PRESSURE (MPA)
100
75
50
25
0
-25
20
25
30
35
40
45
TIME (MS)

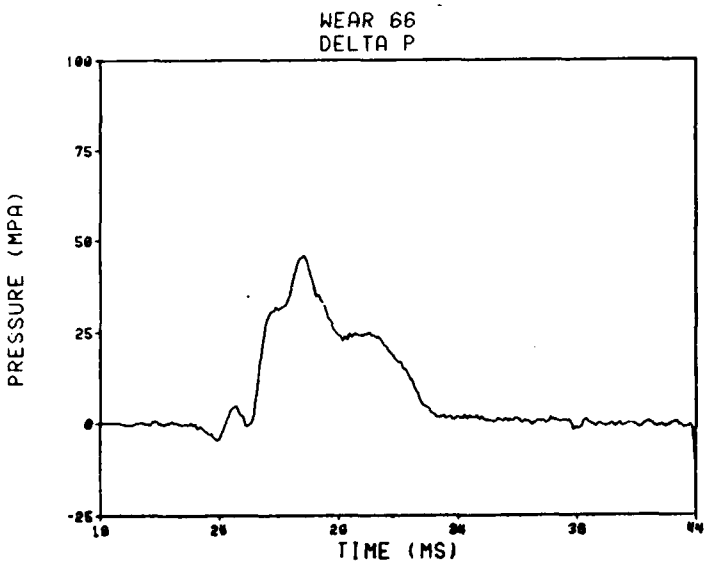

WEAR 64
TC @ 0, 90, 180 DEG
DELTA TEMP (DEG C)
150
125
100
75
50
25
0
0
50
100
150
200
250
300
TIME (MS)

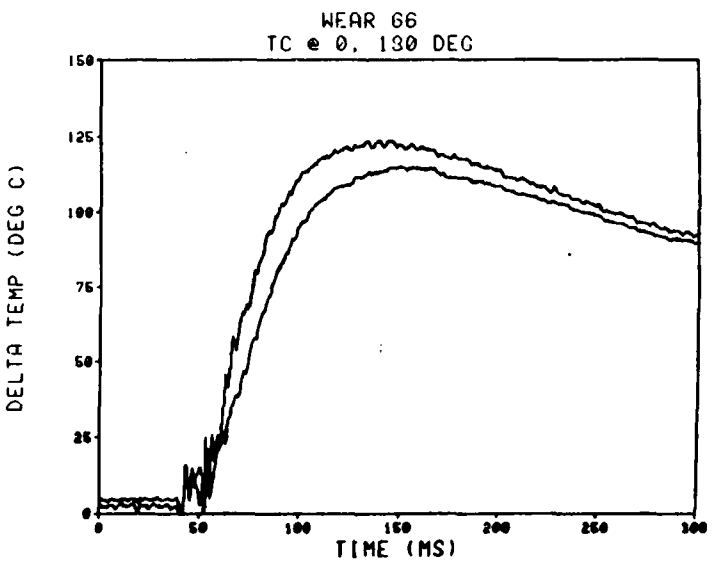

WEAR 65
BREECH & FORWARD PRESSURE
PRESSURE (MPA)
TIME (MS)

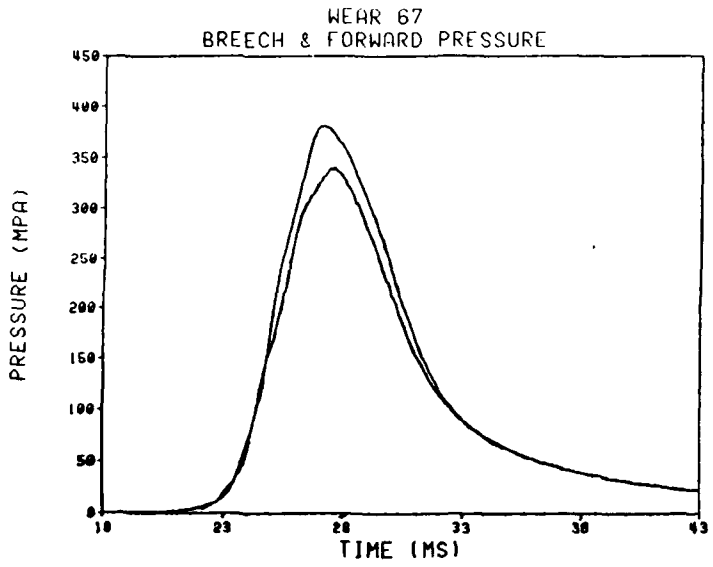

WEAR 65
DELTA P
PRESSURE (MPA)
TIME (MS)

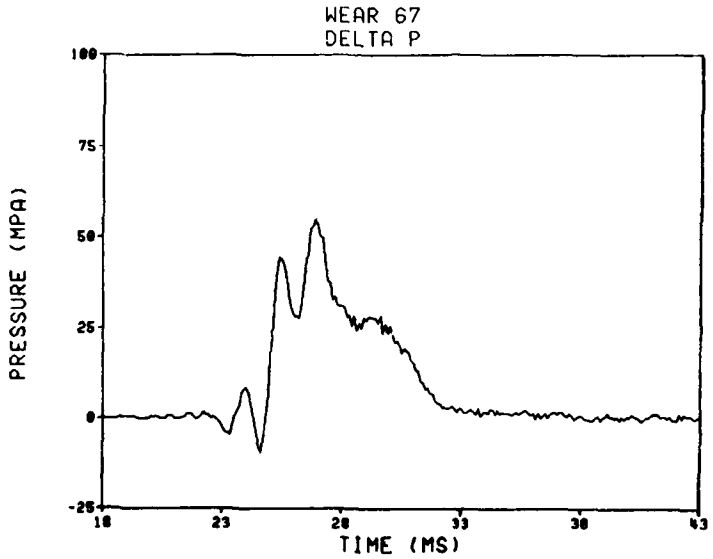

WEAR 65
TC @ 0, 90, 180 DEG
DELTA TEMP (DEG C)
TIME (MS)

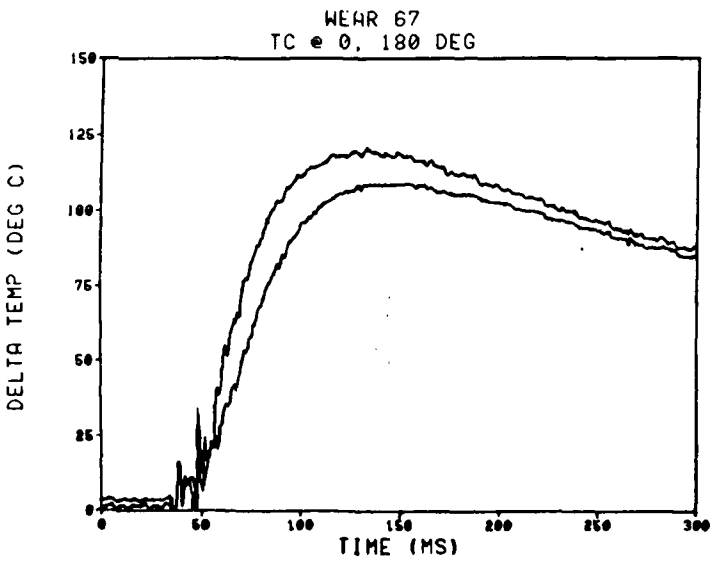

WEAR 66
BREECH & FORWARD PRESSURE
PRESSURE (MPA)
TIME (MS)

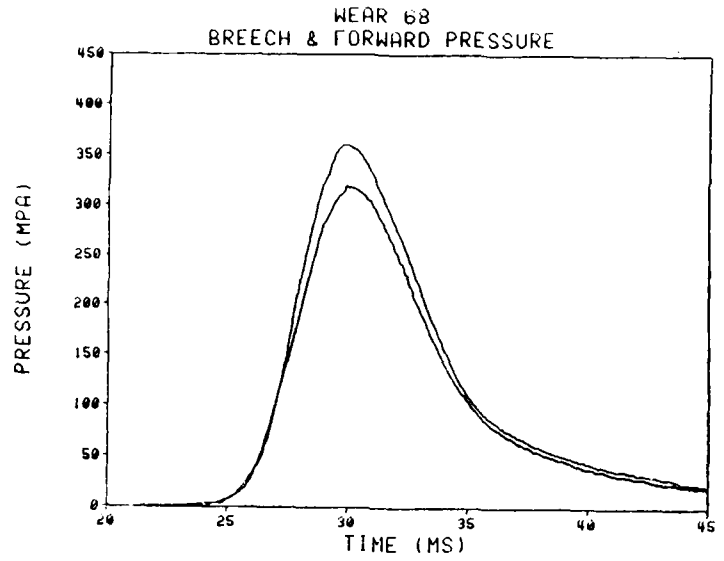

WEAR 66
DELTA P
PRESSURE (MPA)
TIME (MS)

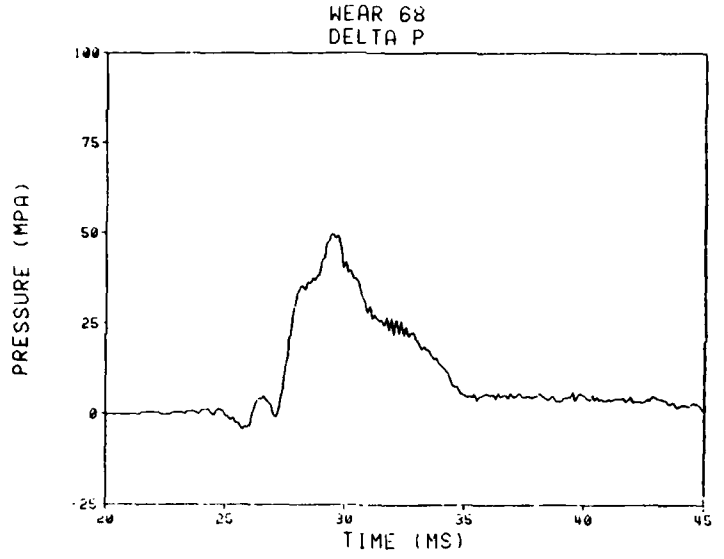

WEAR 66
TC @ 0. 130 DEG
DELTA TEMP (DEG C)
TIME (MS)

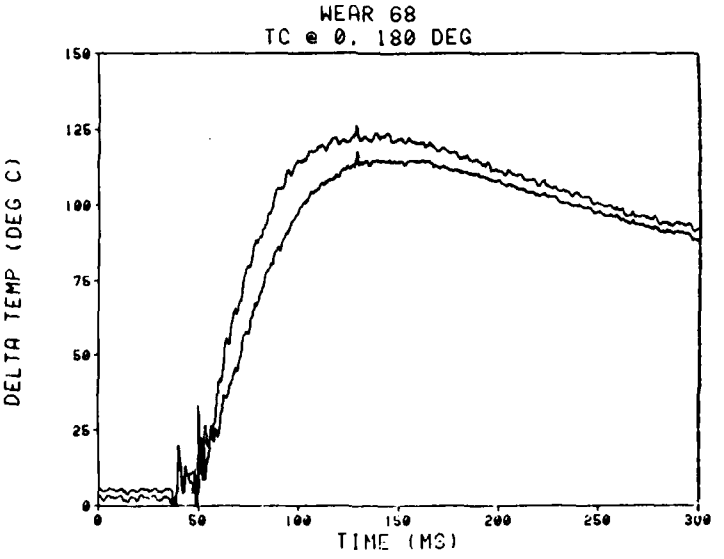

WEAR 67
BREECH & FORWARD PRESSURE
PRESSURE (MPA)
450
400
350
300
250
200
150
100
50
0
18
23
28
33
38
43
TIME (MS)

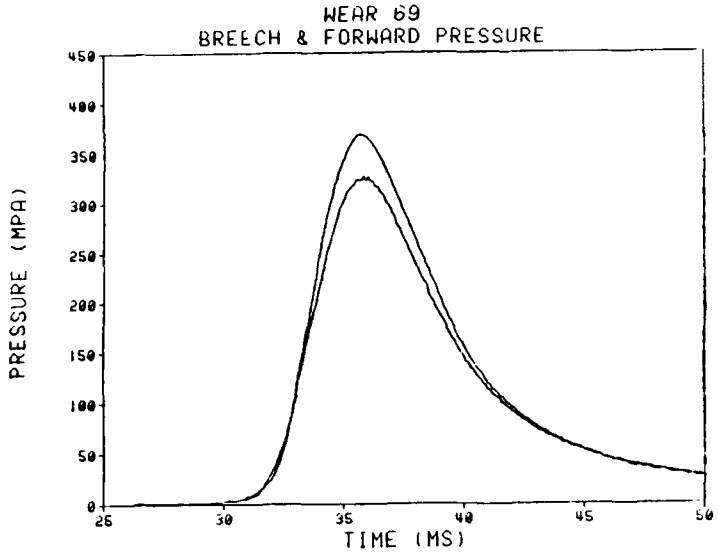

WEAR 67
DELTA P
PRESSURE (MPA)
100
75
50
25
0
-25
18
23
28
33
38
43
TIME (MS)

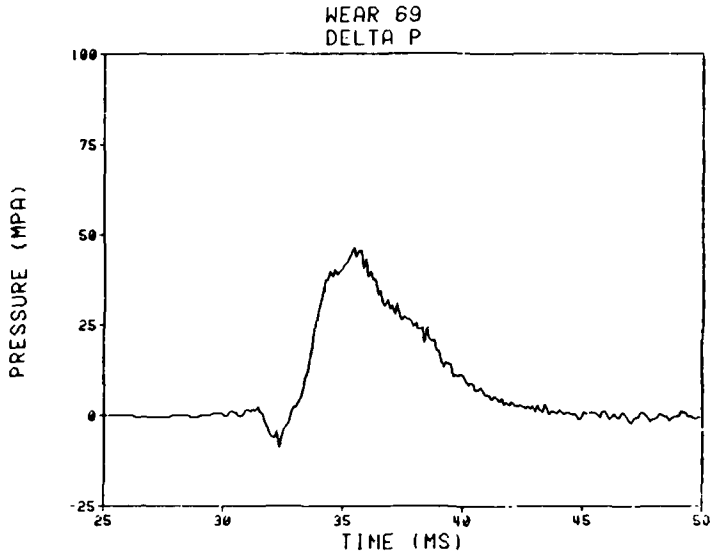

WEAR 67
TC @ 0, 180 DEG
DELTA TEMP (DEG C)
150
125
100
75
50
25
0
0
50
100
150
200
250
300
TIME (MS)


WEAR 68
BREECH & FORWARD PRESSURE
PRESSURE (MPA)
TIME (MS)


WEAR 68
DELTA P
PRESSURE (MPA)
TIME (MS)


WEAR 68
TC @ 0, 180 DEG
DELTA TEMP (DEG C)
TIME (MS)


WEAR 69
BREECH & FORWARD PRESSURE
PRESSURE (MPA)
450
400
350
300
250
200
150
100
50
0
25
30
35
40
45
50
TIME (MS)


WEAR 69
DELTA P
PRESSURE (MPA)
100
75
50
25
0
-25
25
30
35
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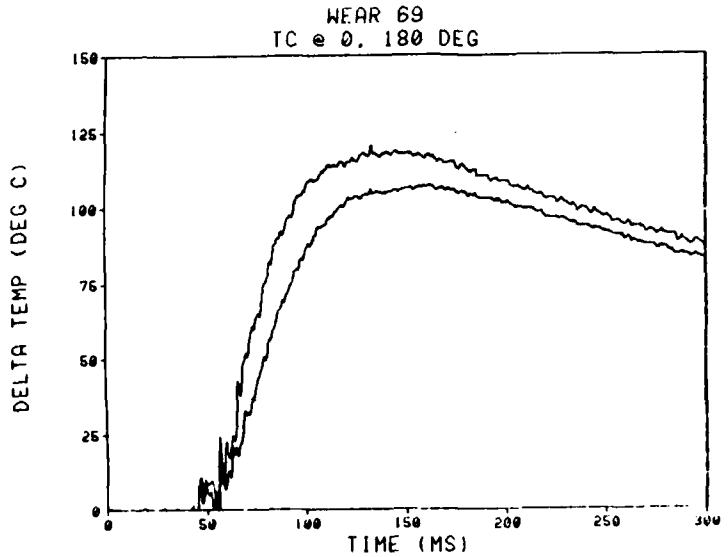
TIME (MS)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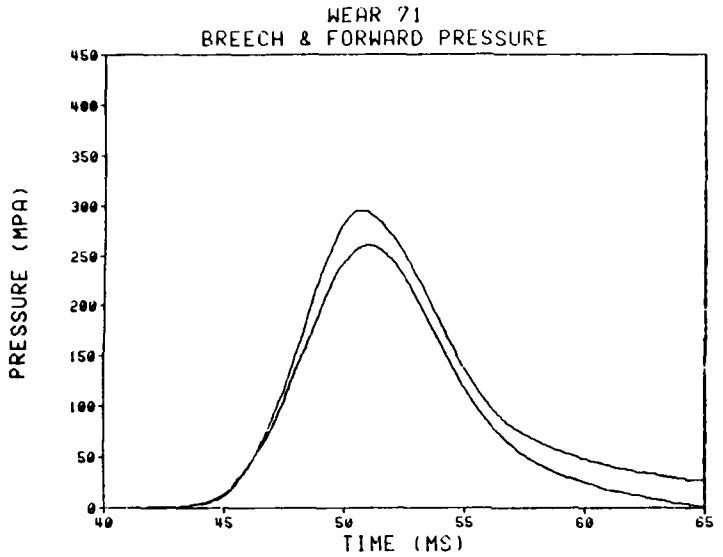
DATA LOST

DATA LOST

DATA LOST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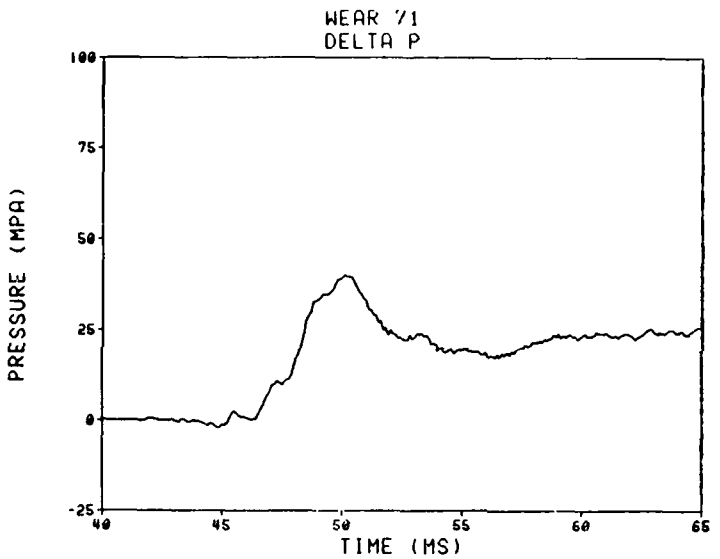
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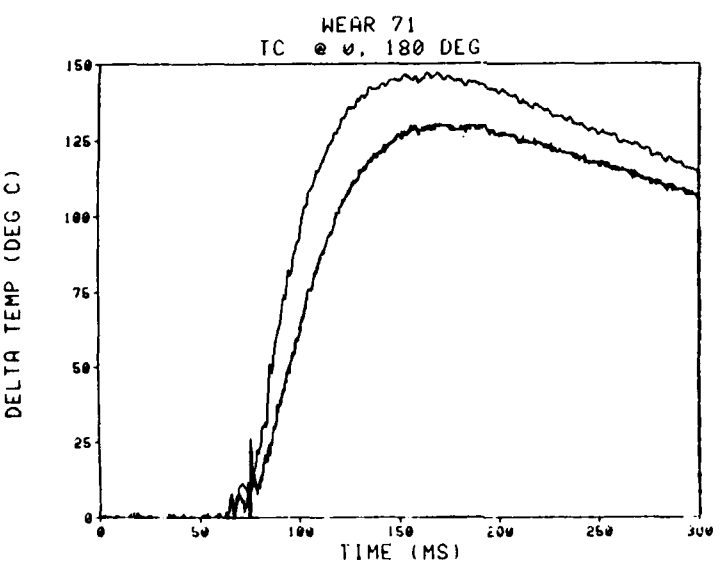
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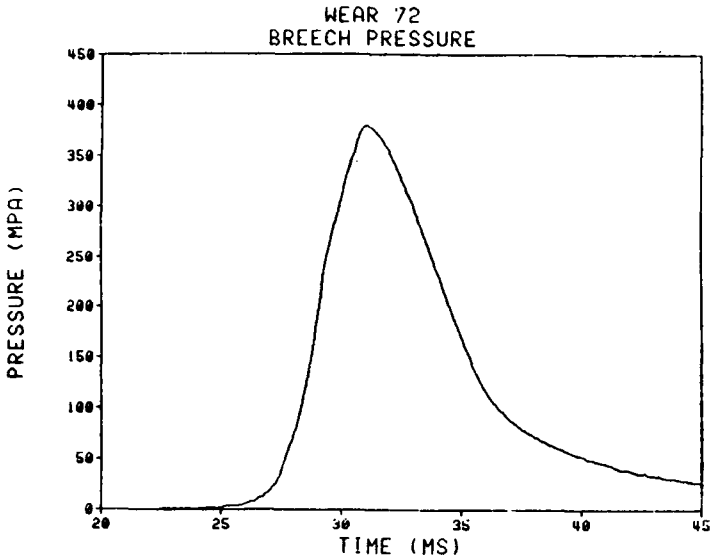
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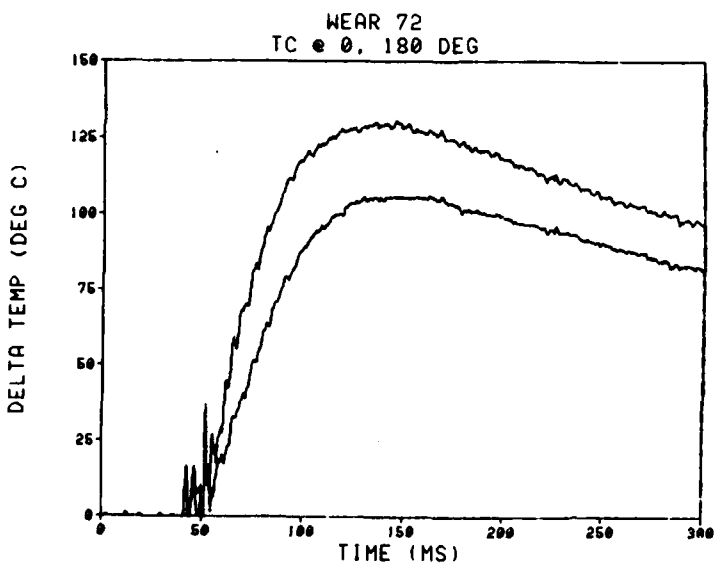
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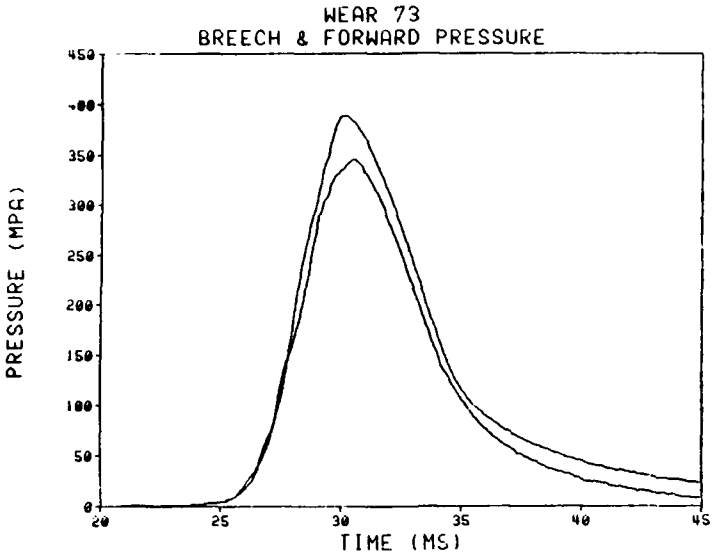
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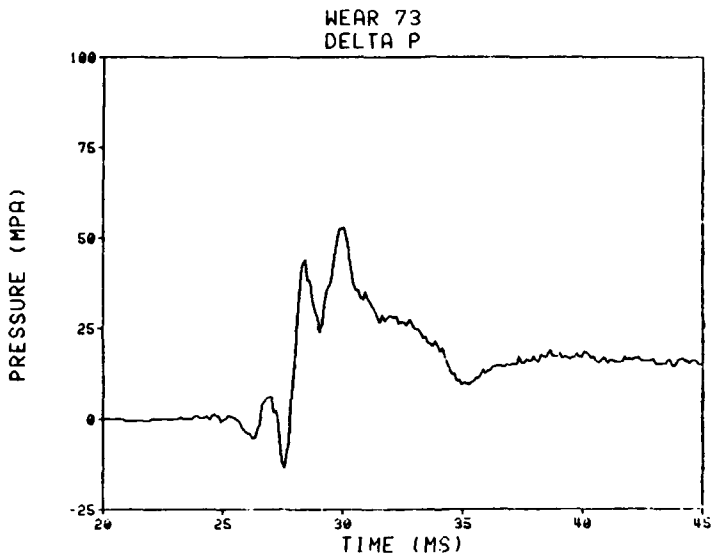
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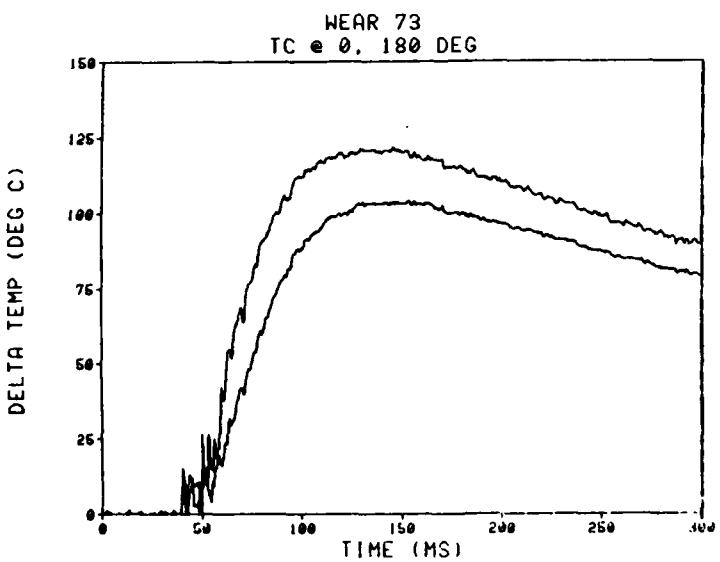
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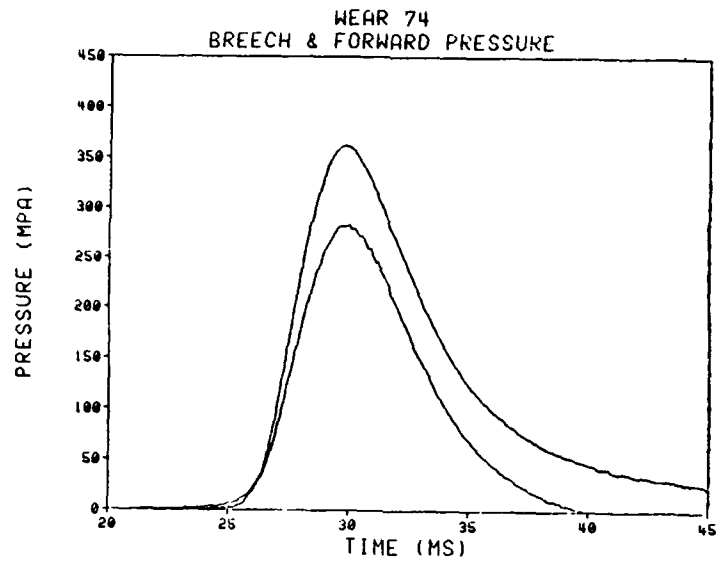
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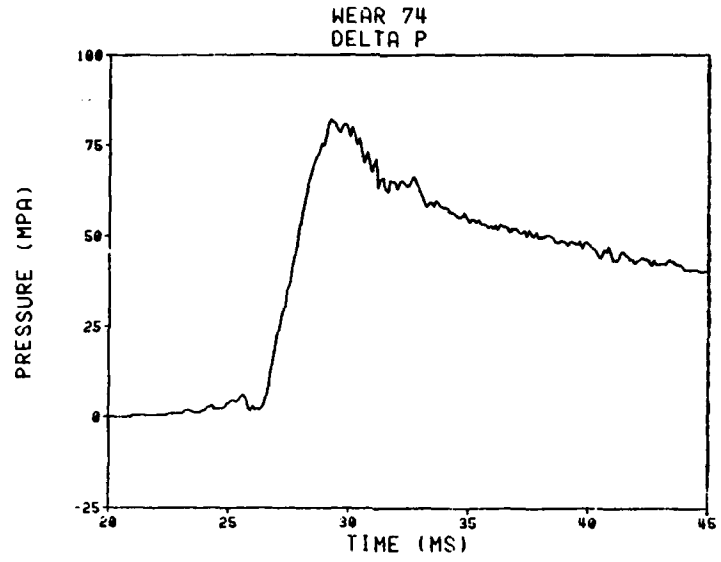
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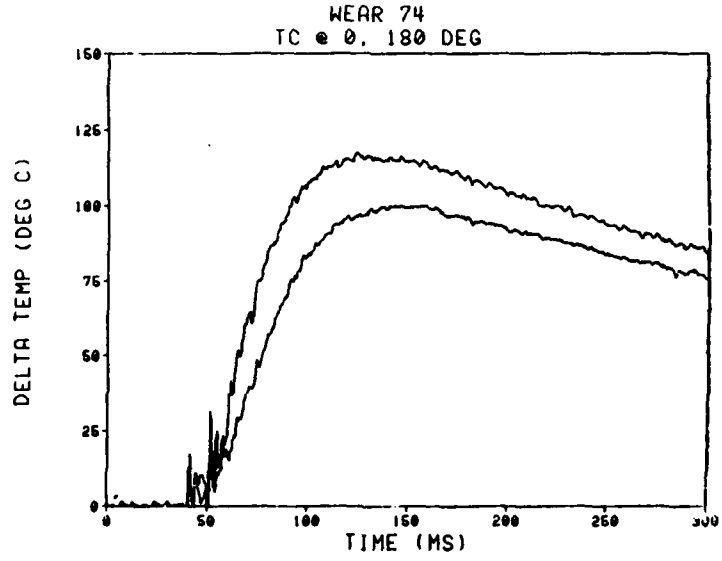
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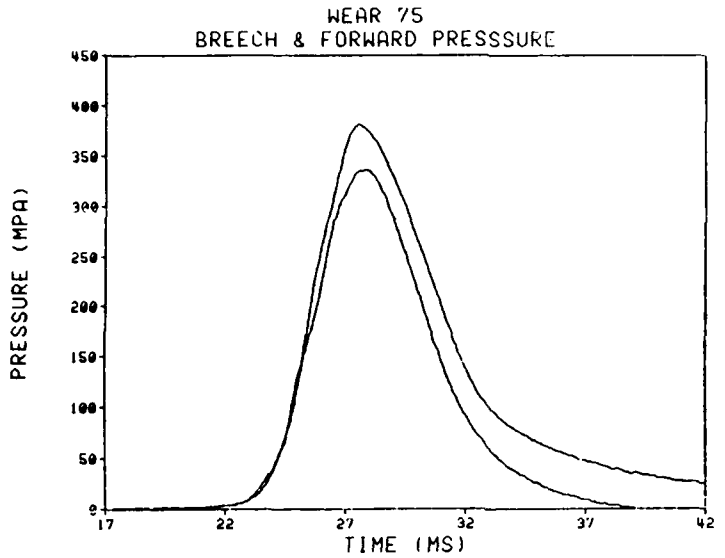
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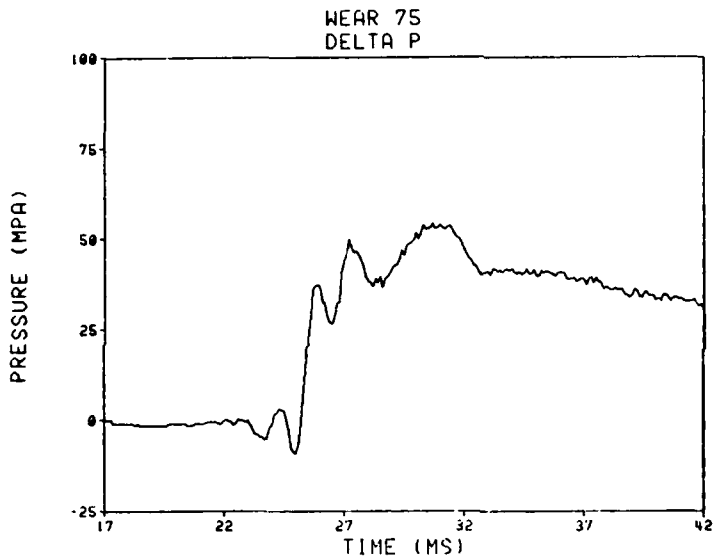
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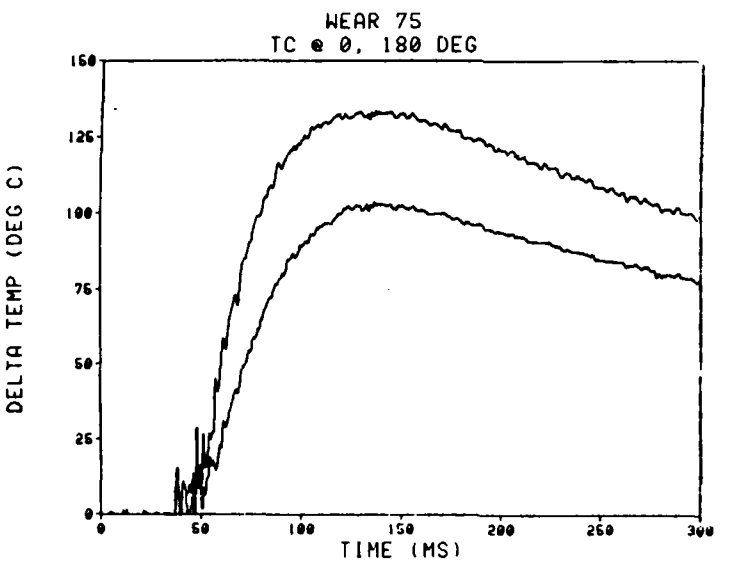
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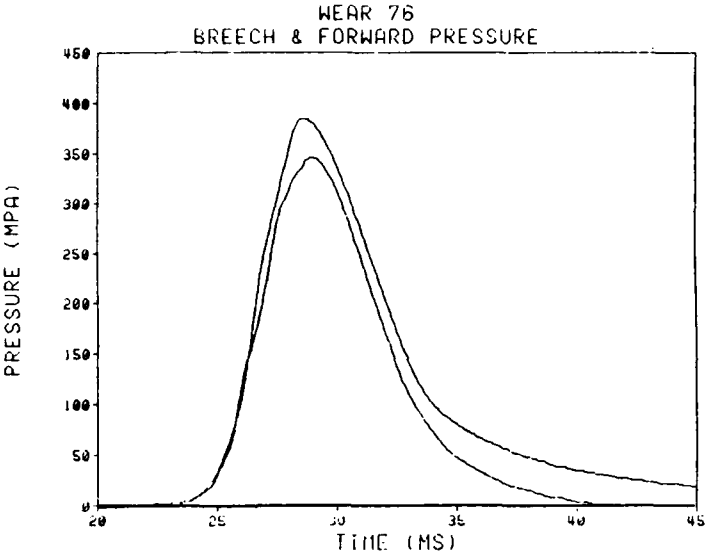
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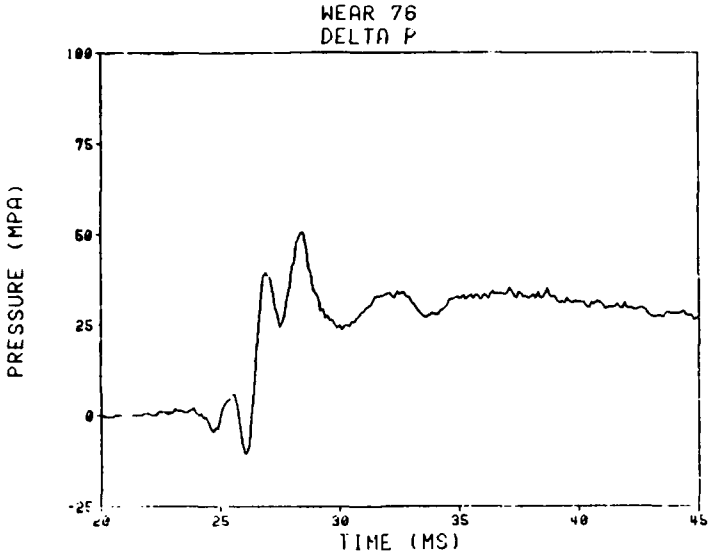
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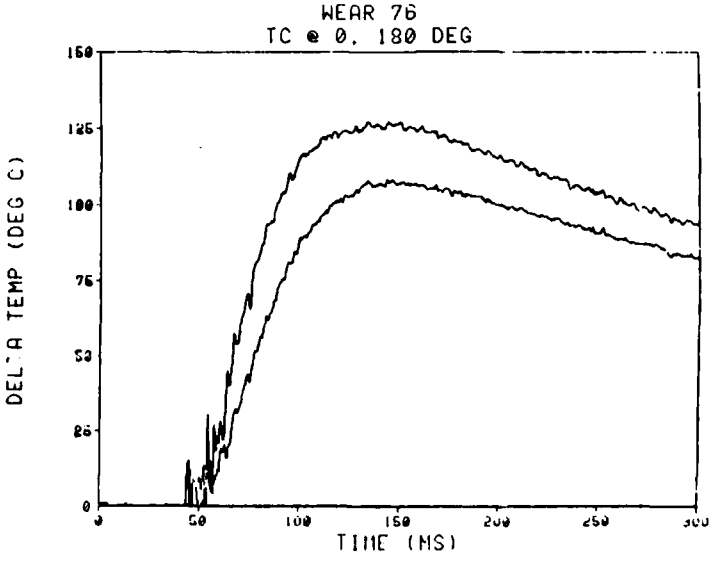
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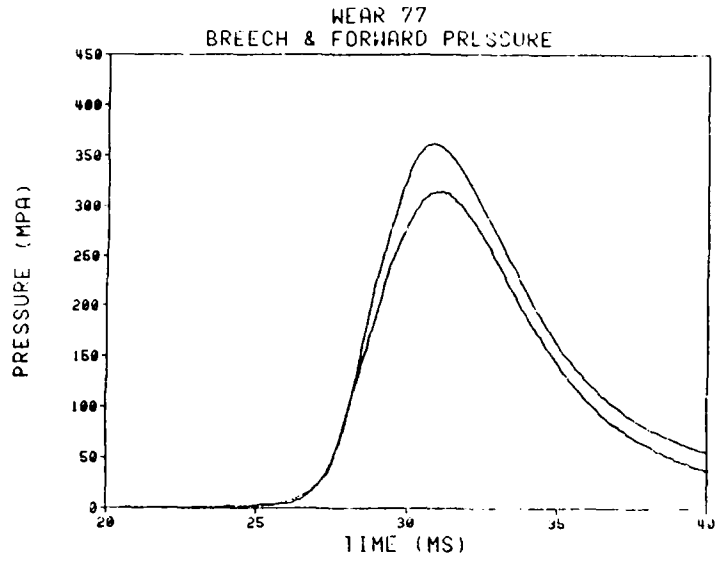
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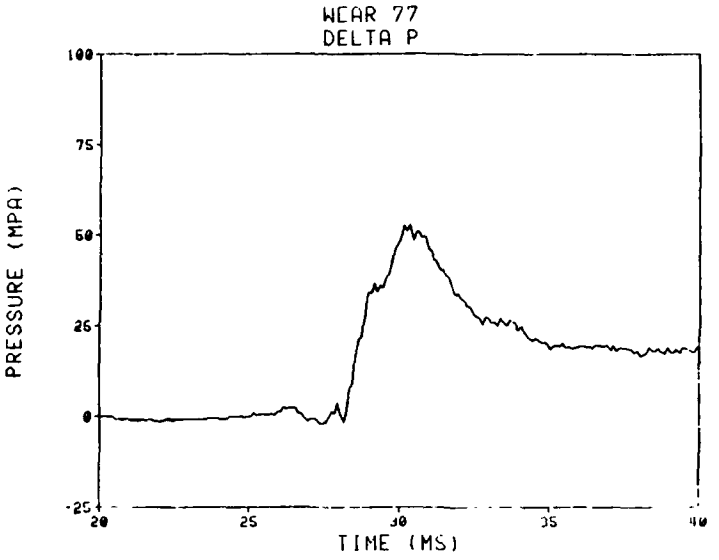
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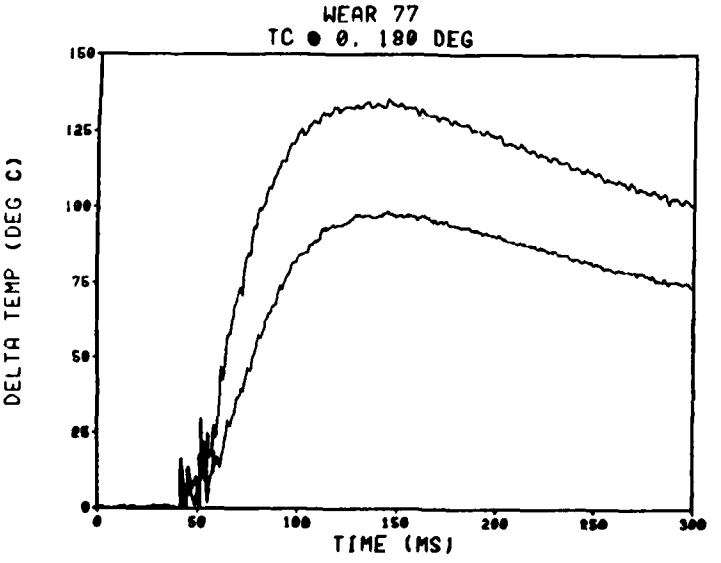
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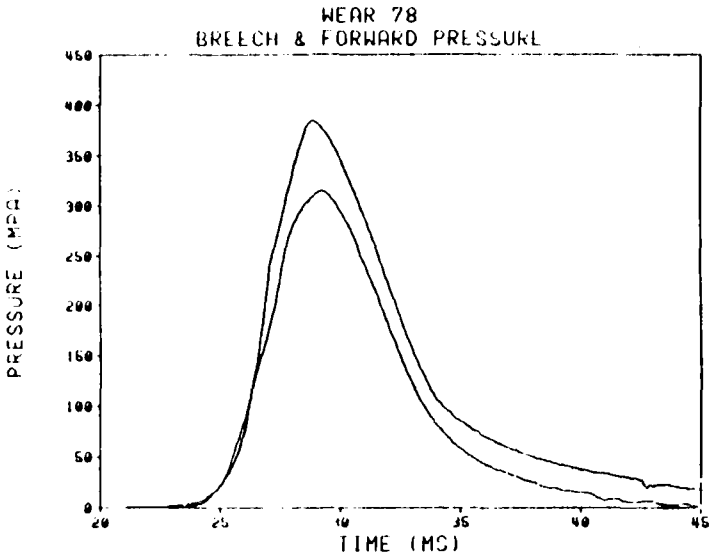
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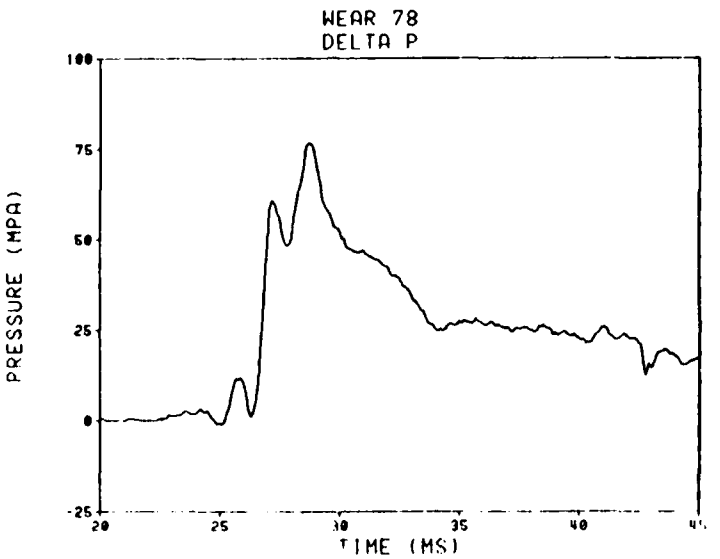
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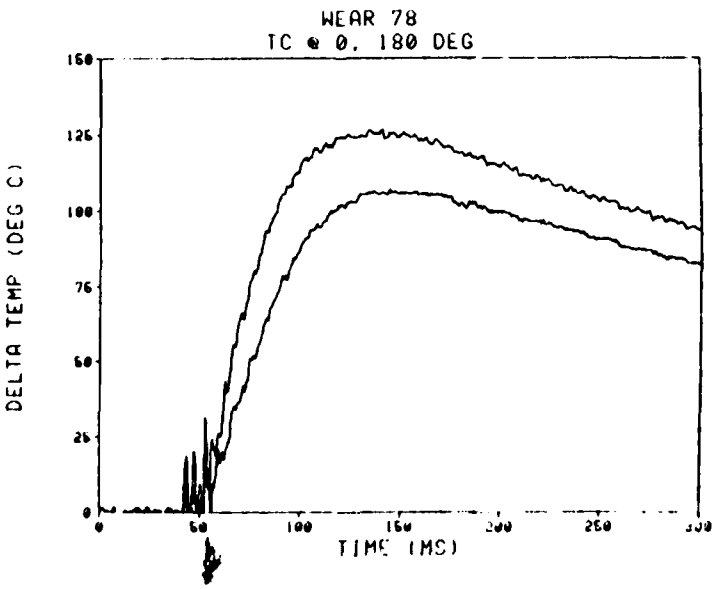
WEAR 78
TC @ 0, 180 DEG
DELTA TEMP (DEG C)
TIME (MS)

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